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(54) **MAGNETIC INDUCTION PLASMA SOURCE FOR SEMICONDUCTOR PROCESSES AND EQUIPMENT**

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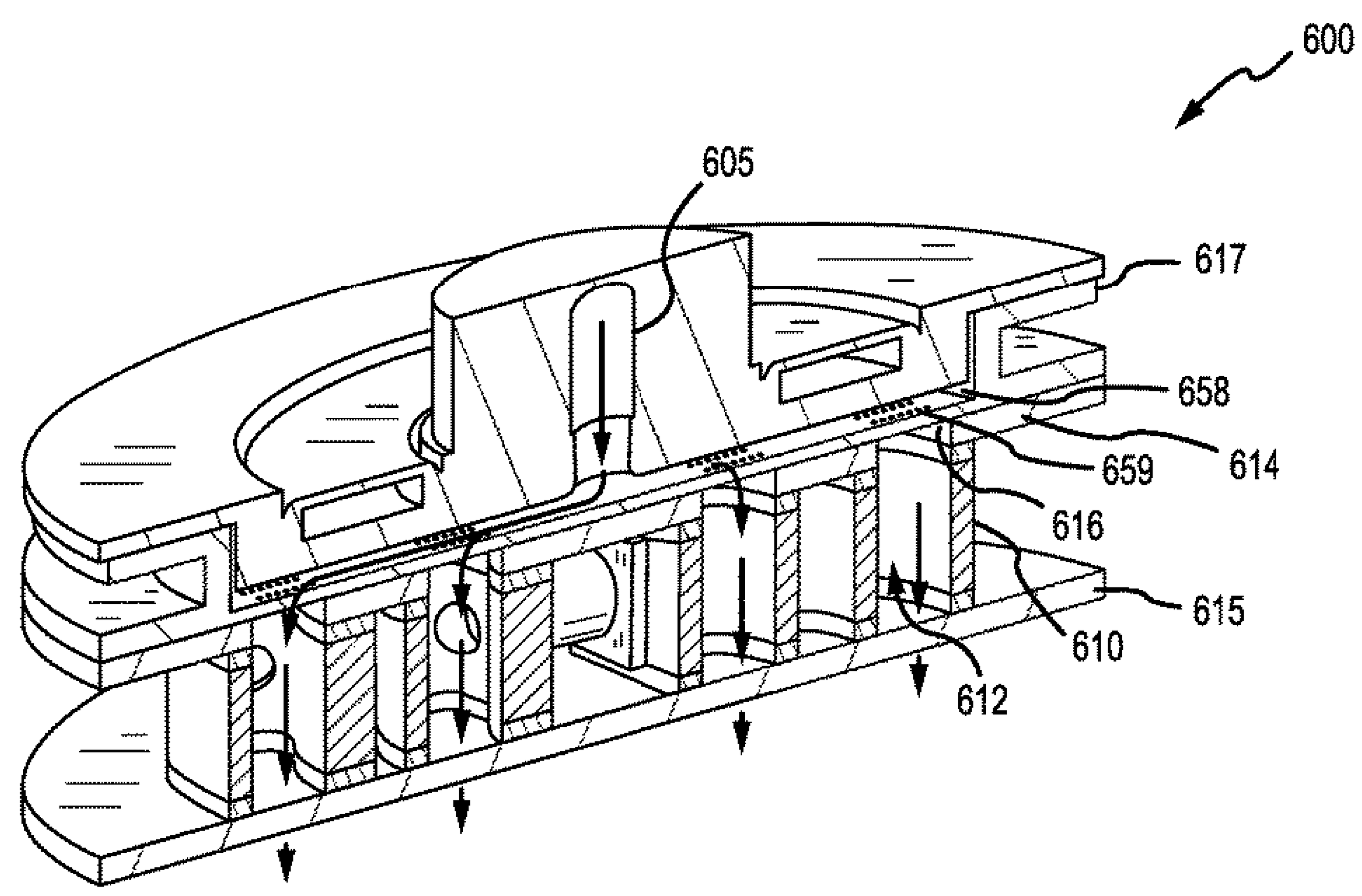
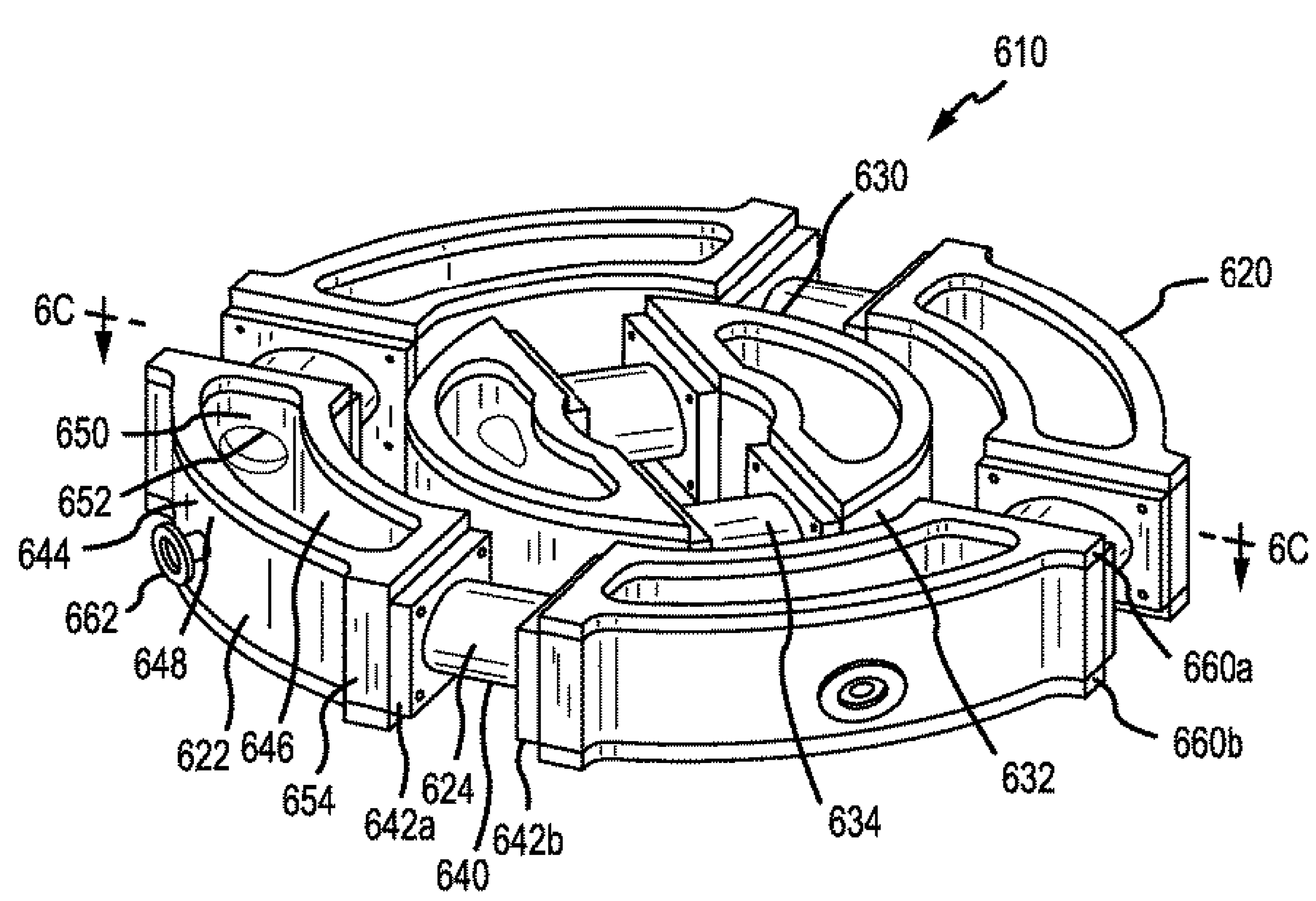
(57) **ABSTRACT**

Exemplary magnetic induction plasma systems for generating plasma products are provided. The magnetic induction plasma system may include a first plasma source including a plurality of first sections and a plurality of second sections arranged in an alternating manner and fluidly coupled with each other such that at least a portion of plasma products generated inside the first plasma source may circulate through at least one of the plurality of first sections and at least one of the plurality of second sections inside the first plasma source. Each of the plurality of second sections may include a dielectric material. The system may further include a plurality of first magnetic elements each of which may define a closed loop. Each of the plurality of second sections may define a plurality of recesses for receiving one of the plurality of first magnetic elements therein.

**20 Claims, 9 Drawing Sheets**



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See application file for complete search history.

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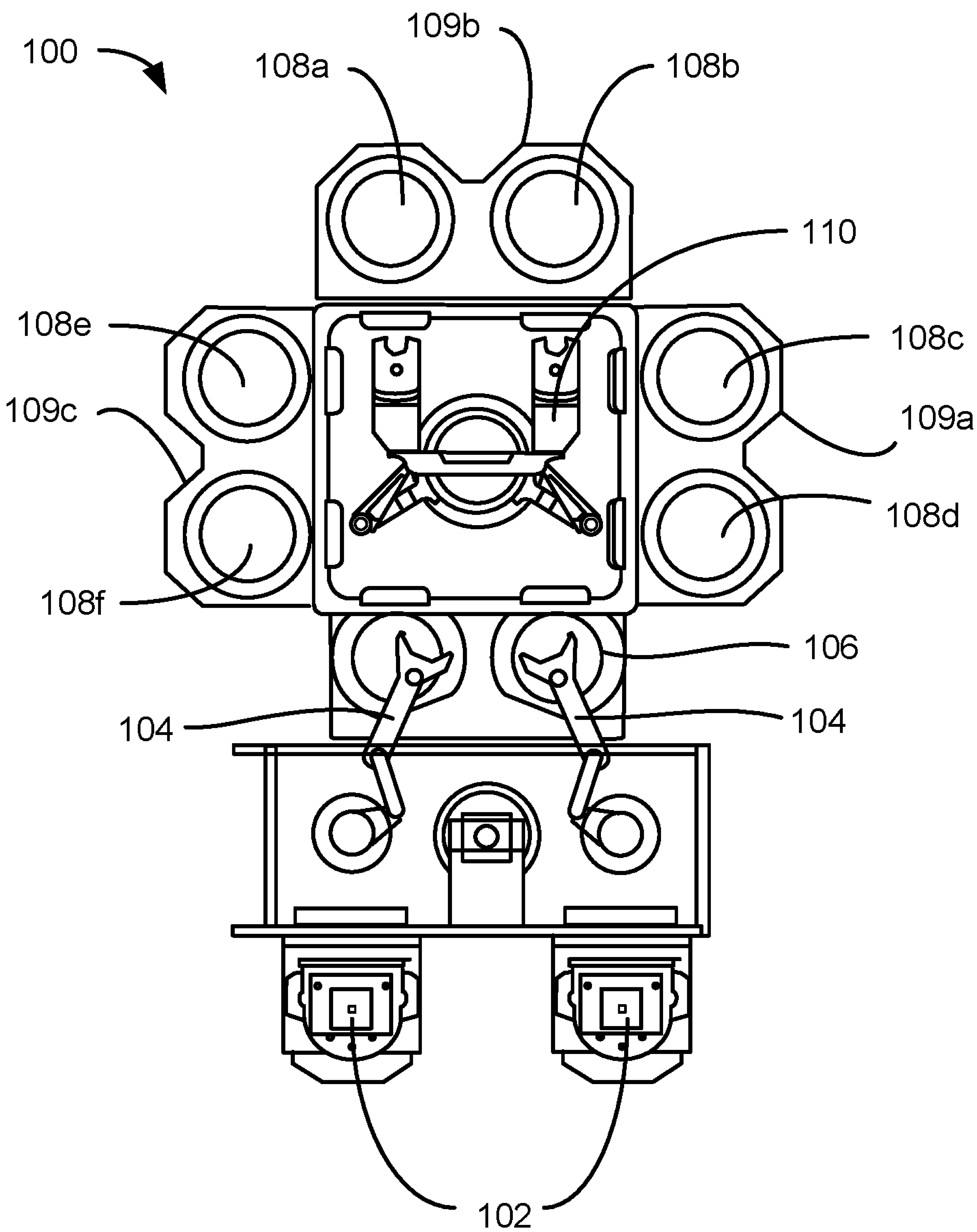
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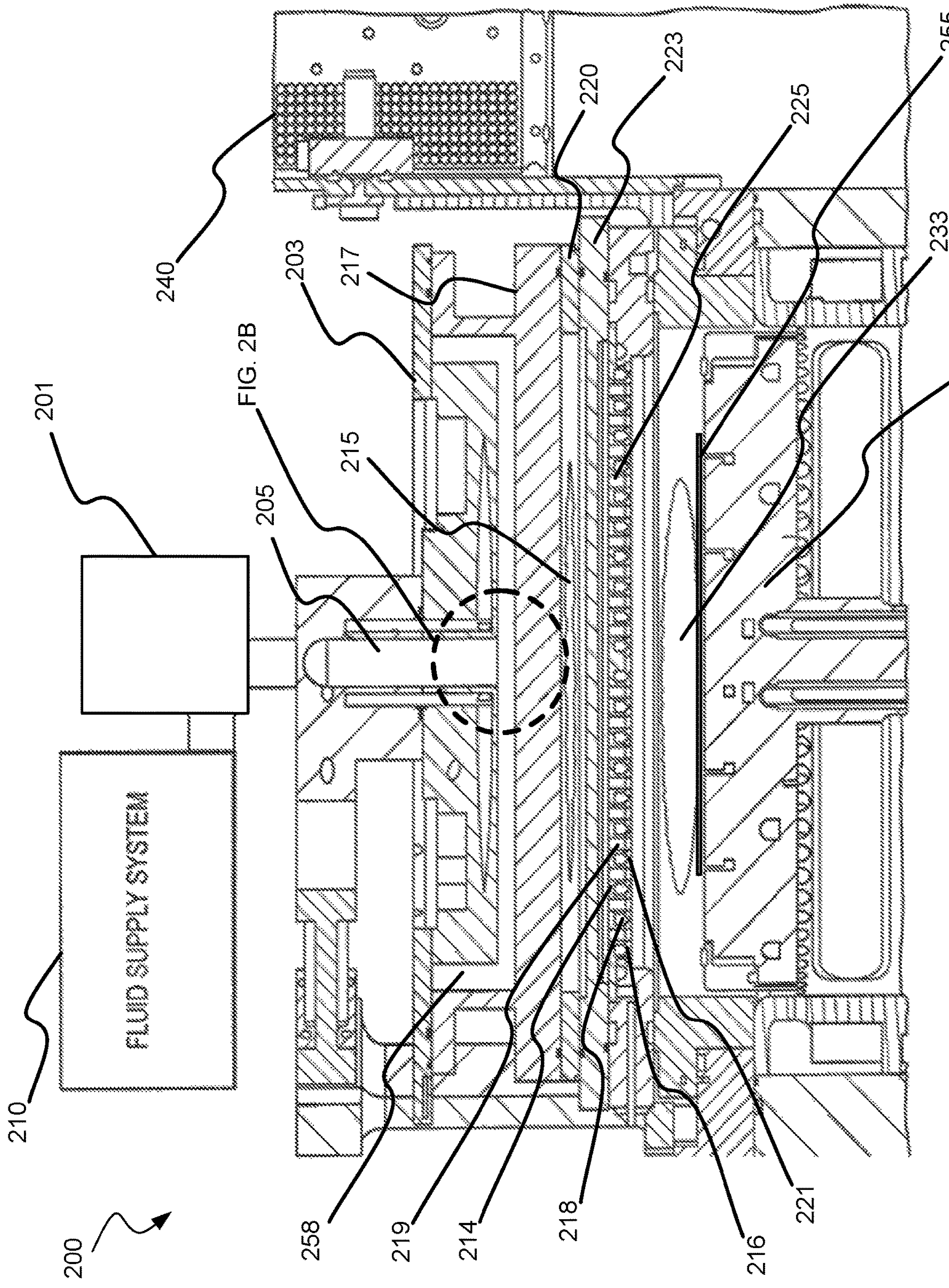
104
104
102

FIG. 1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203
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210
FLUID SUPPLY SYSTEM
FIG. 2B
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215
216
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219
220
221
223
225
233
240
255
258
265

*FIG. 2A*

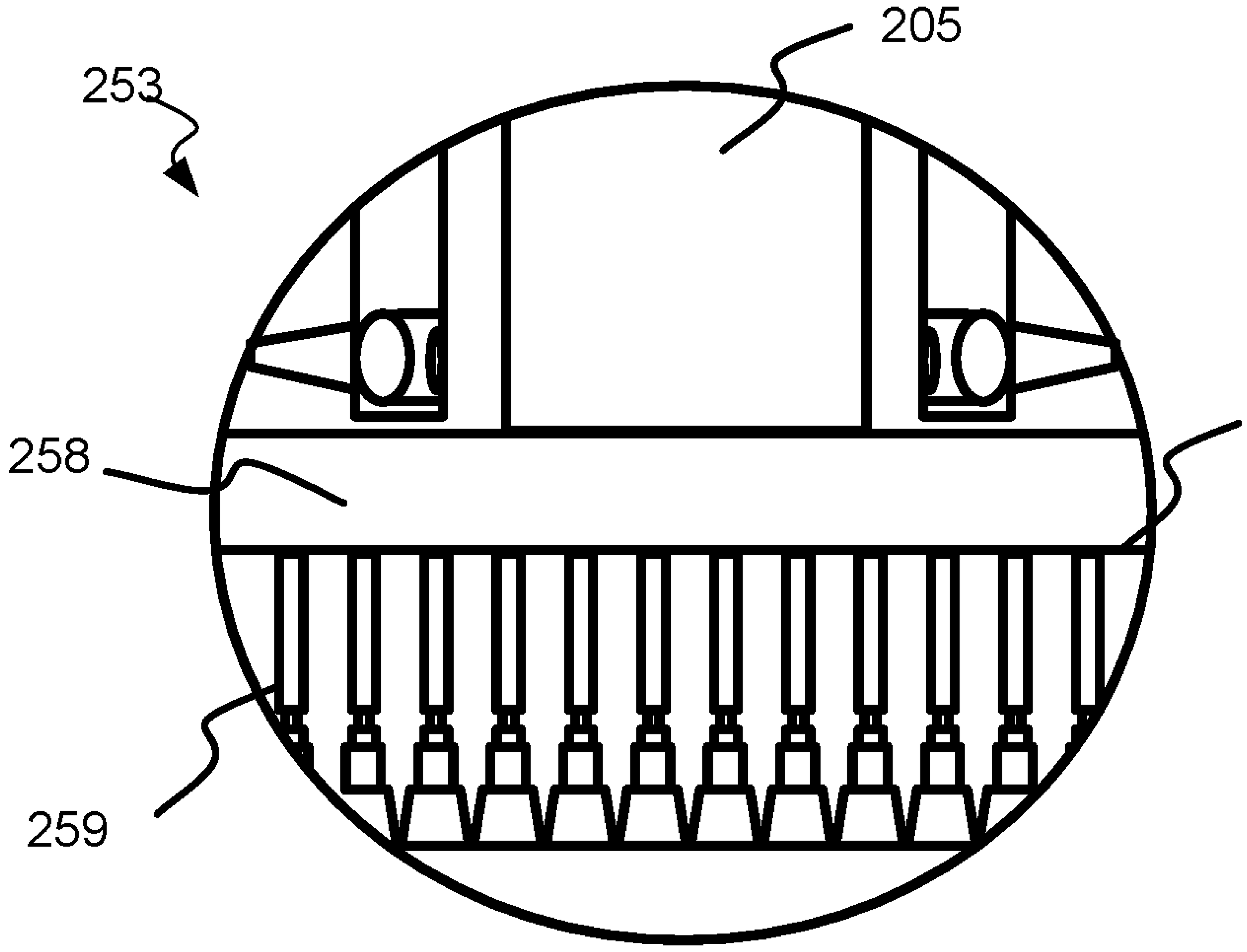



*FIG. 2B*

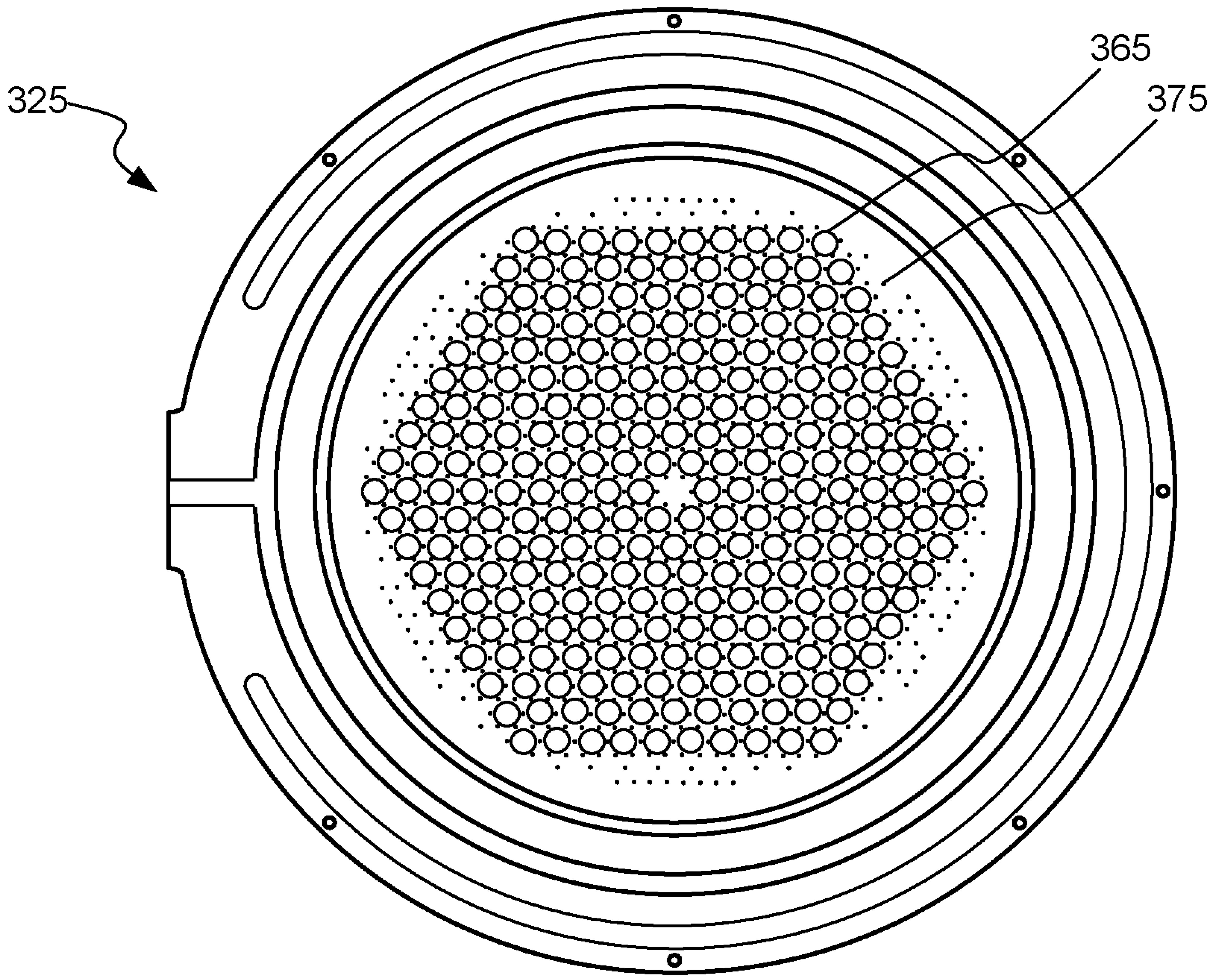



*FIG. 3*

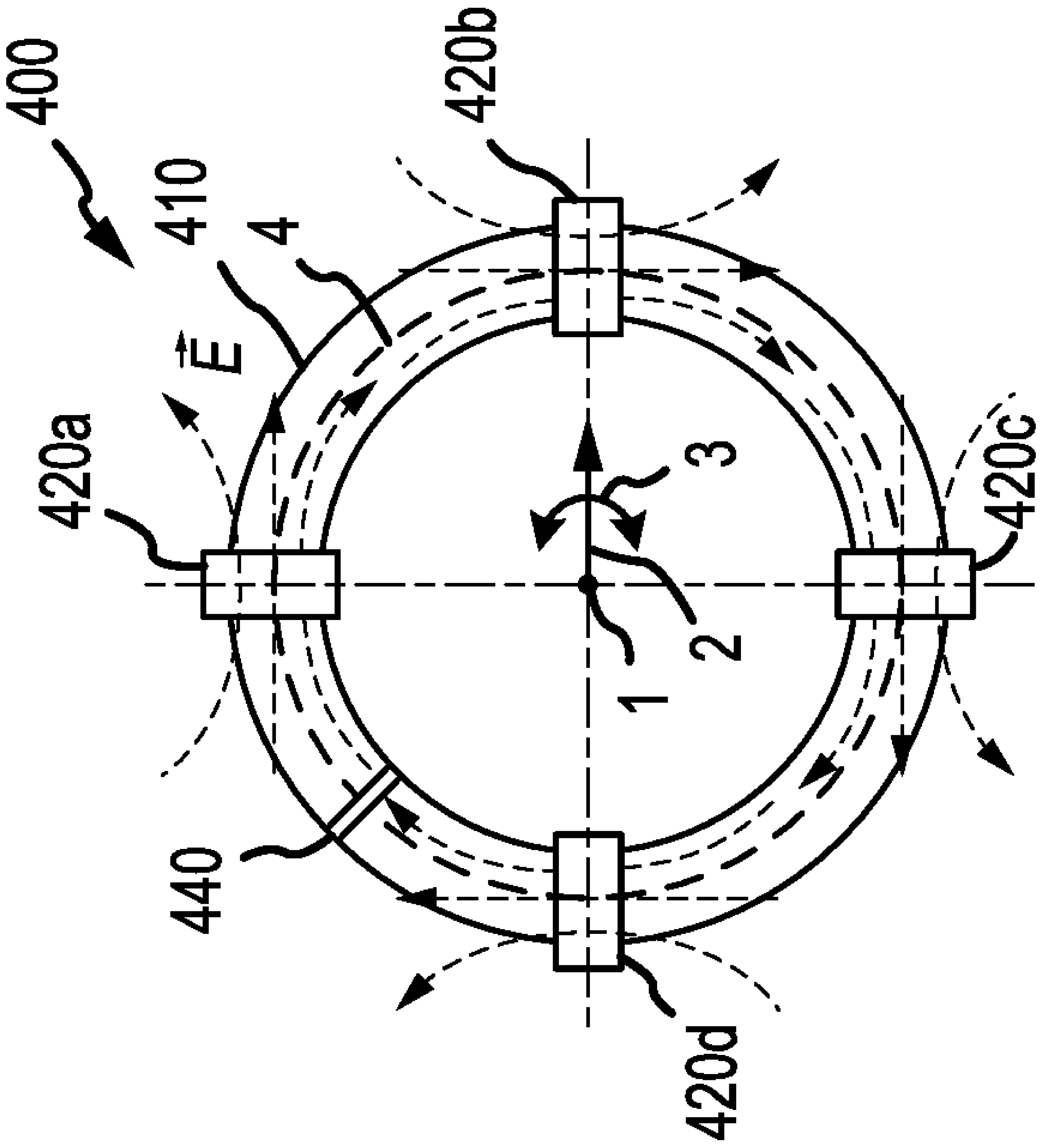



FIG.4A

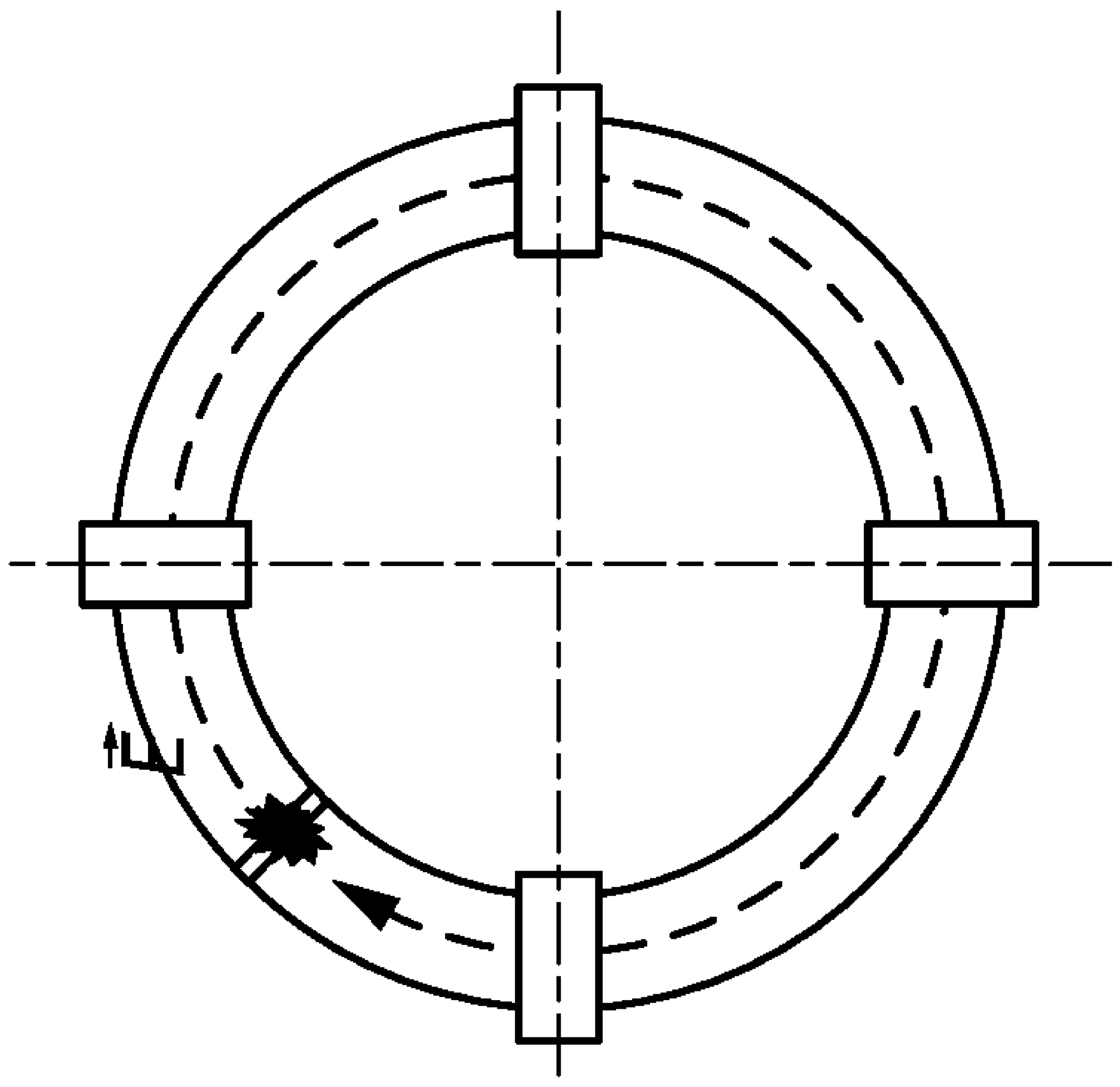



FIG.4B

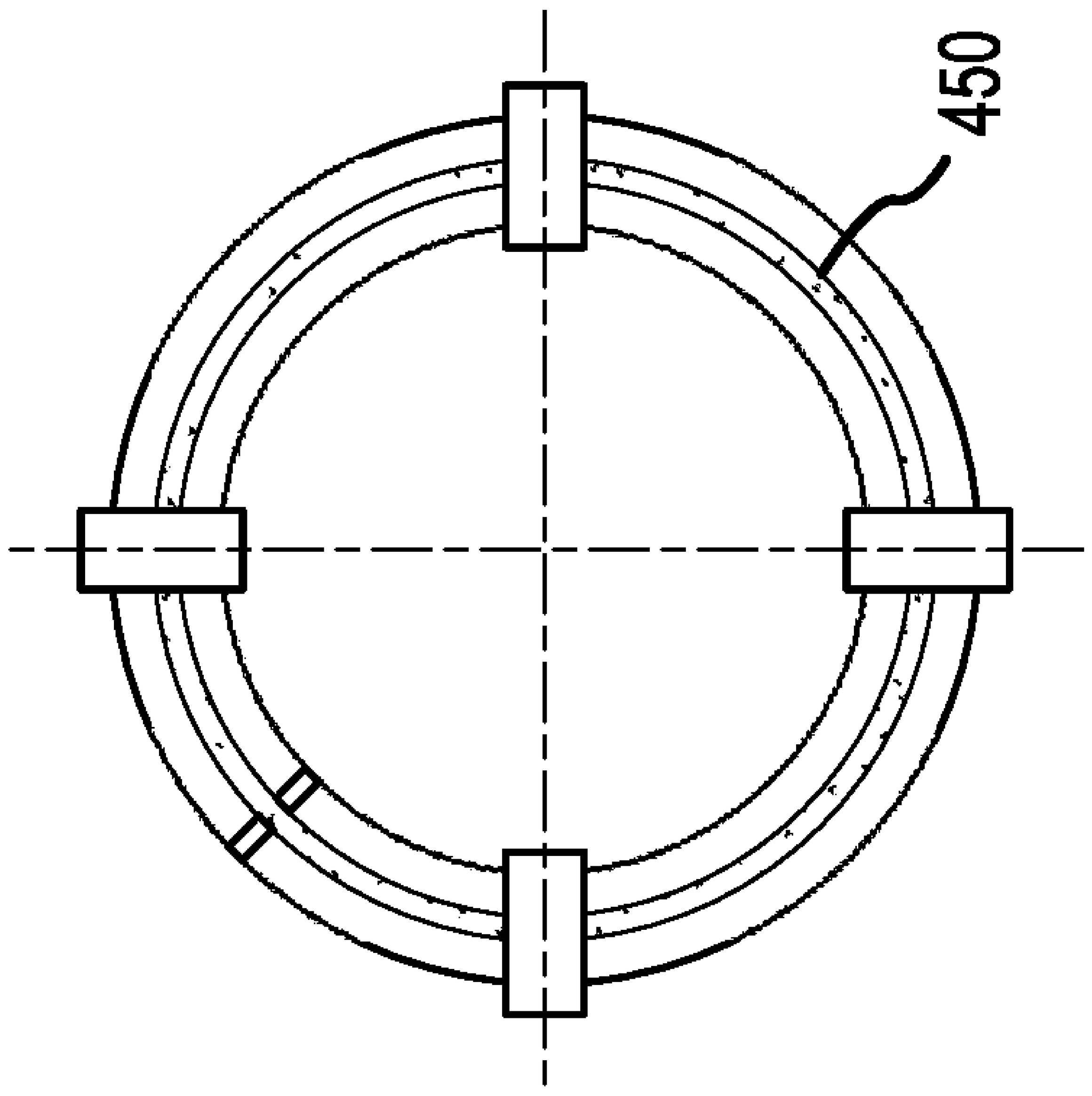



FIG.4C

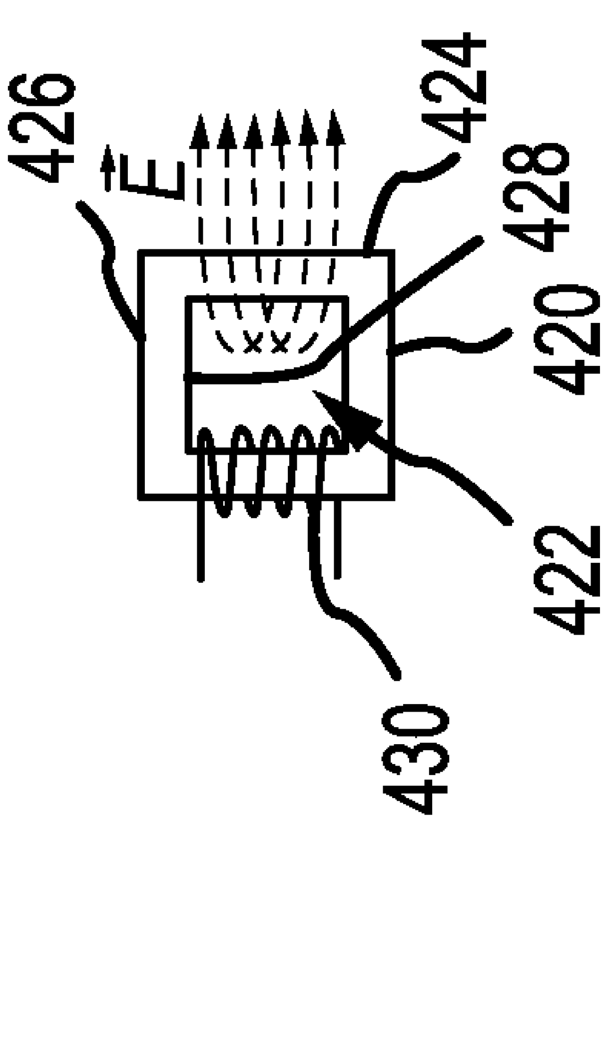



FIG.4D

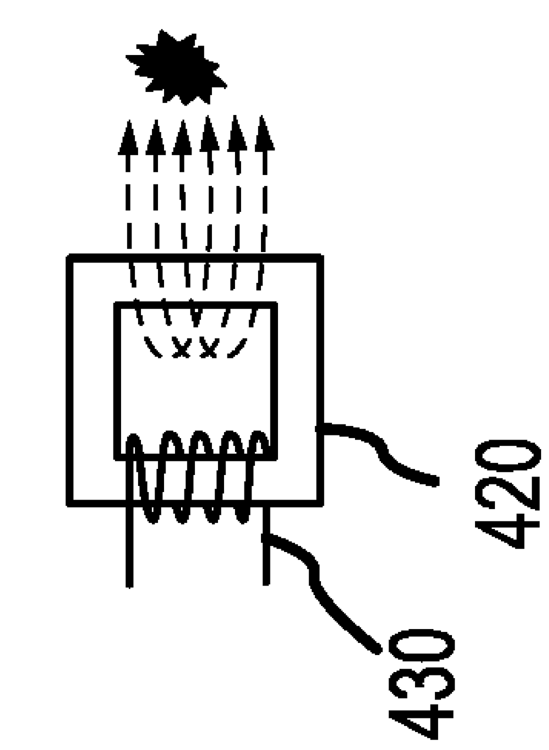



FIG.4E

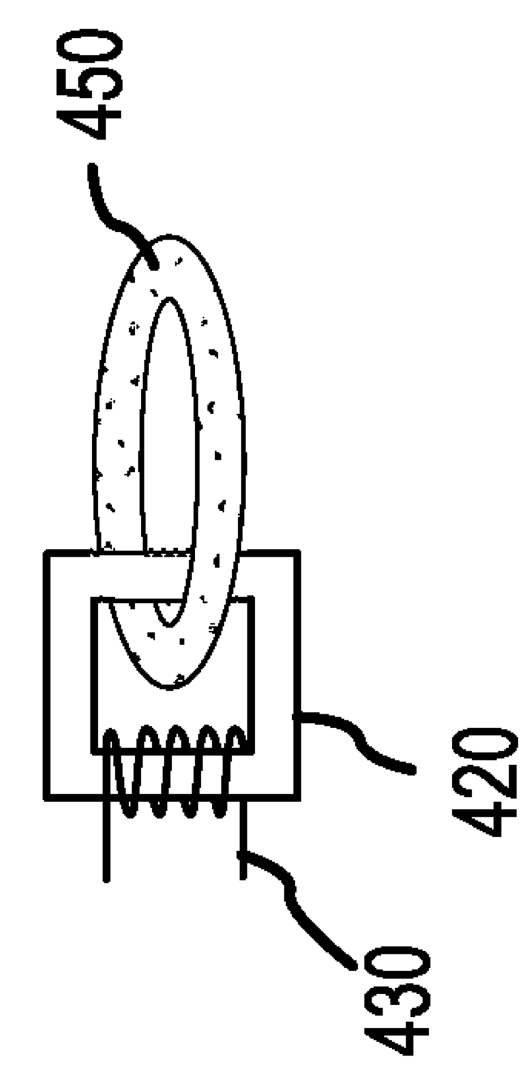



FIG.4F

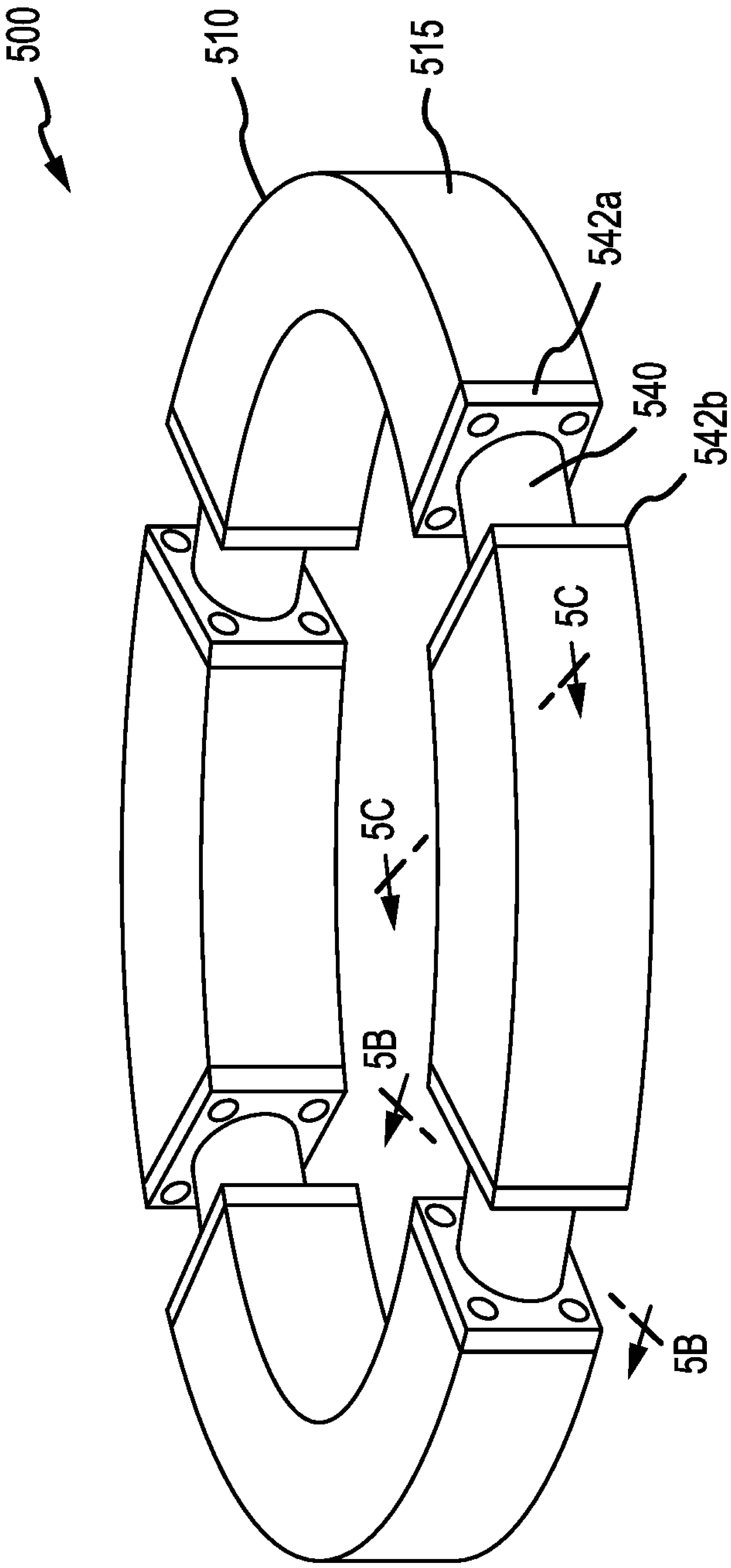



FIG.5A

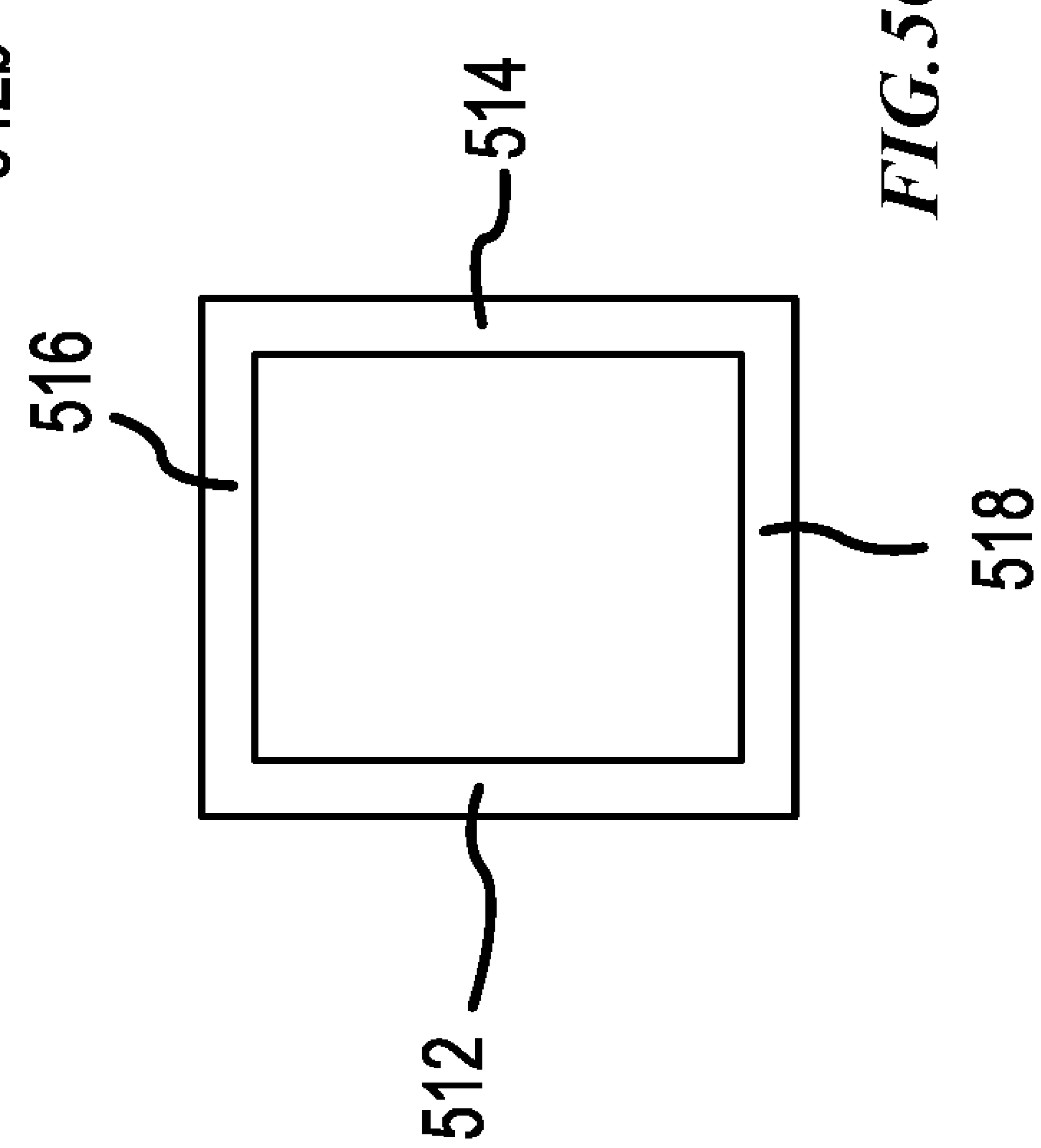



FIG.5C

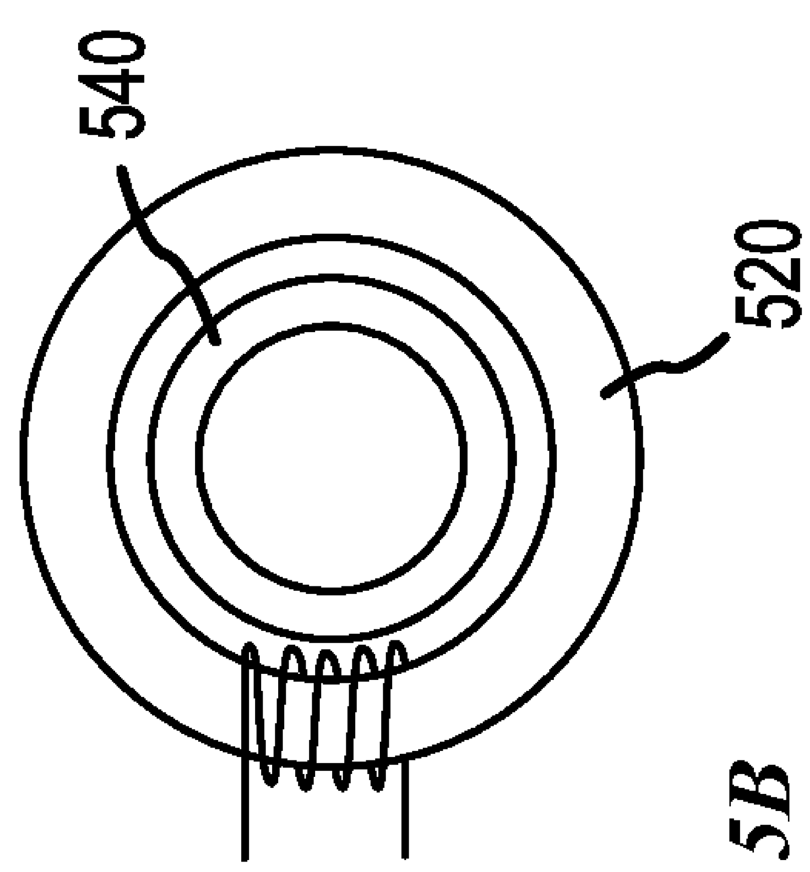



FIG.5B

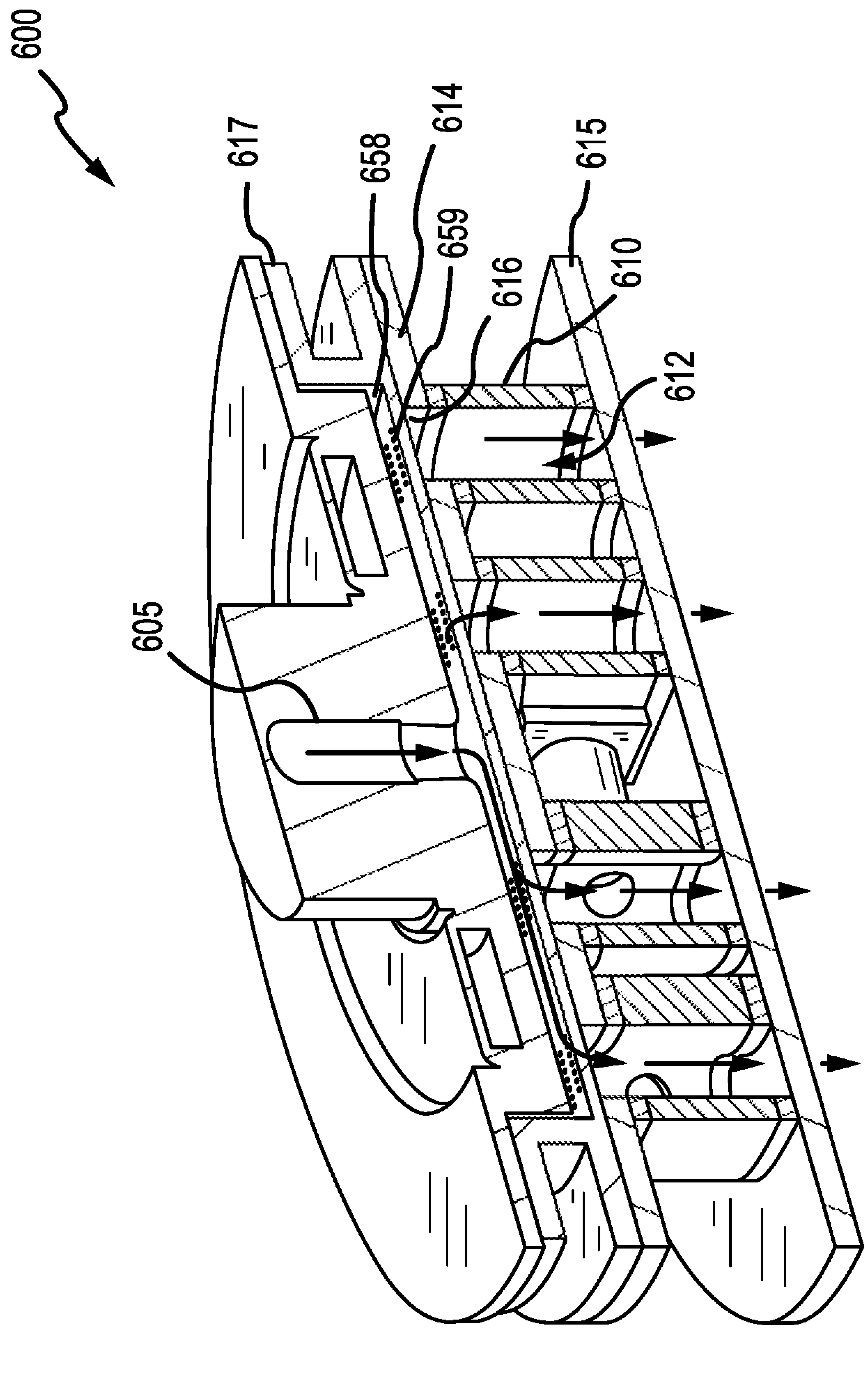
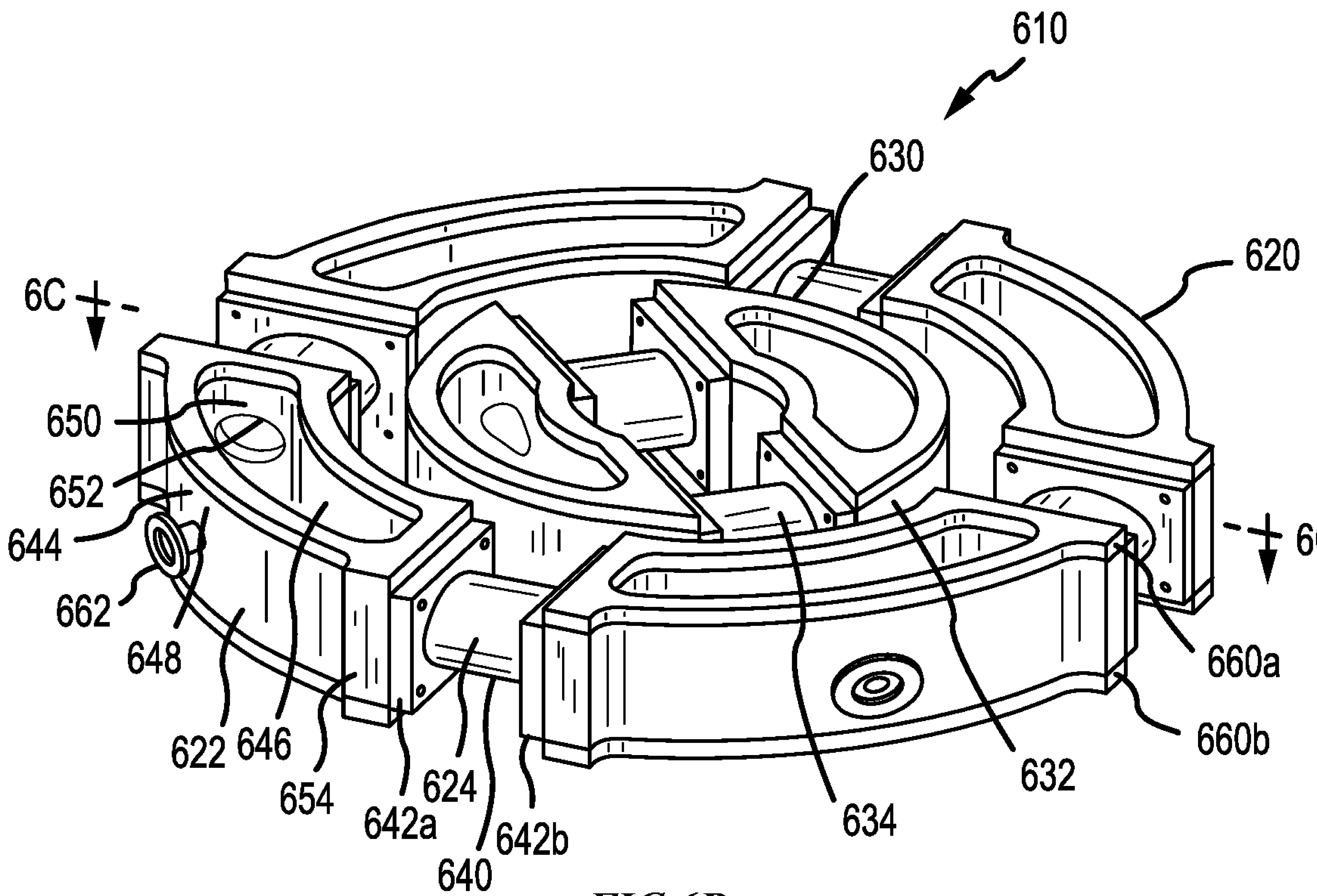



FIG.6A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660a
660b

FIG.6B

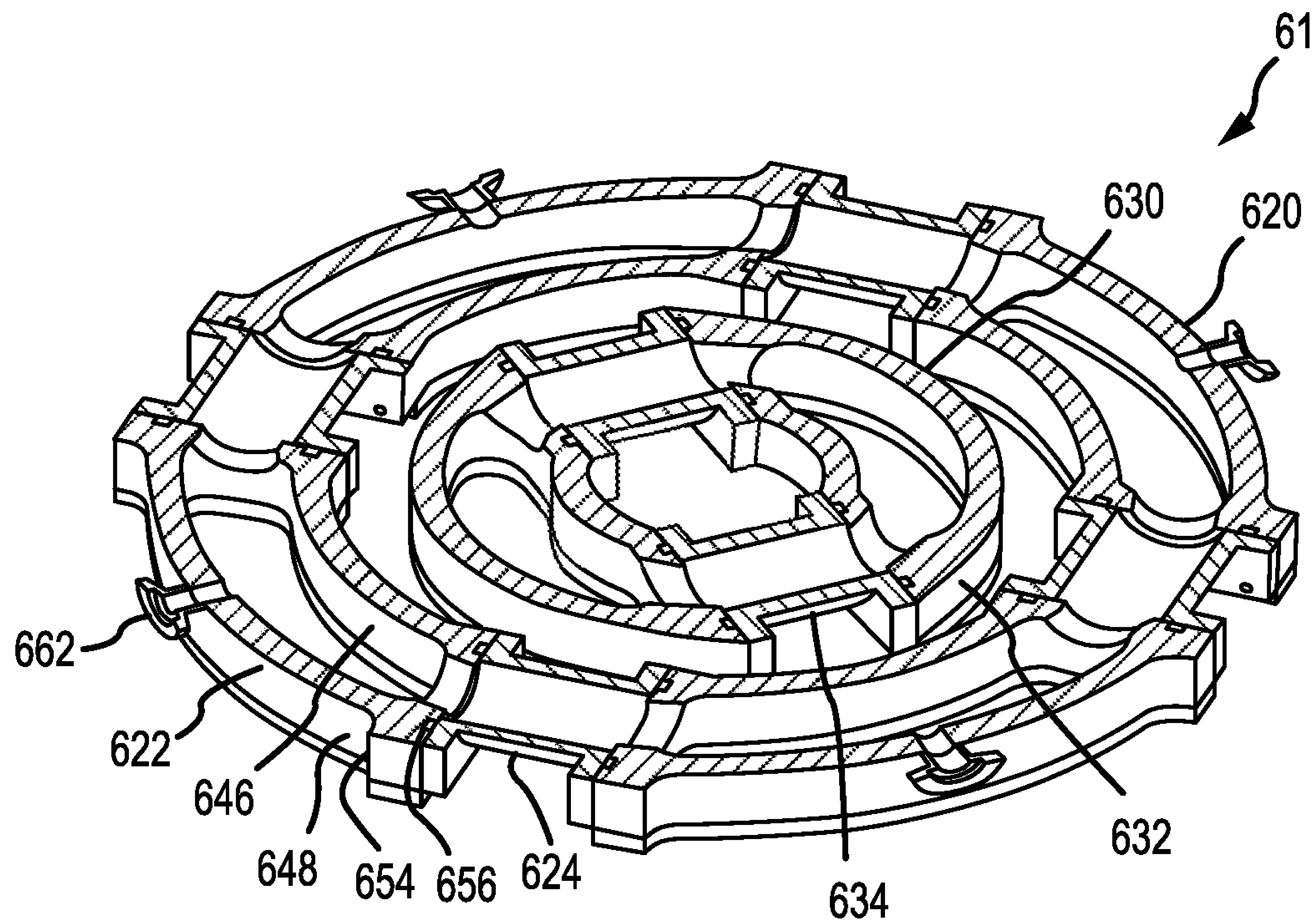
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FIG.6C

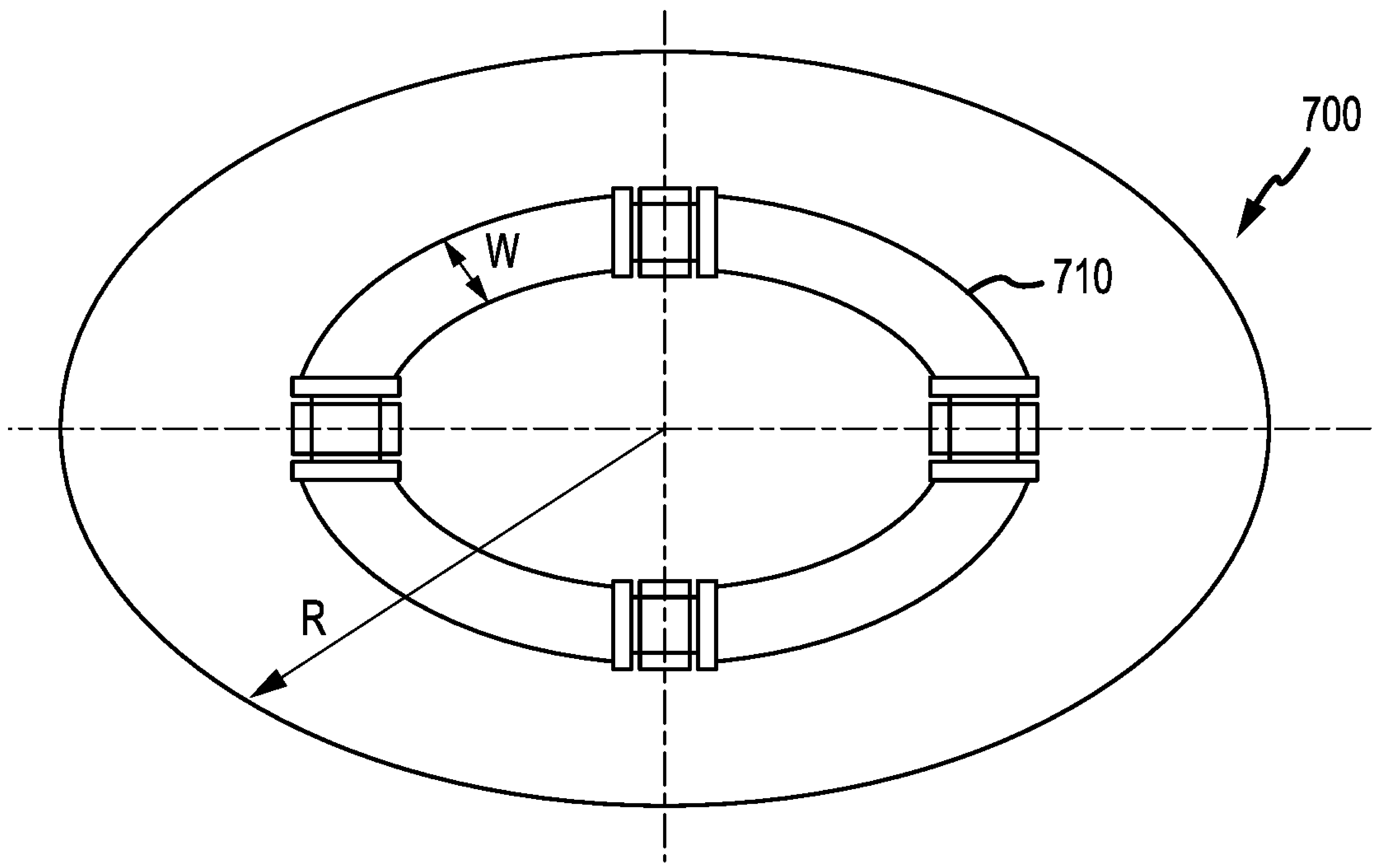


*FIG. 7A*

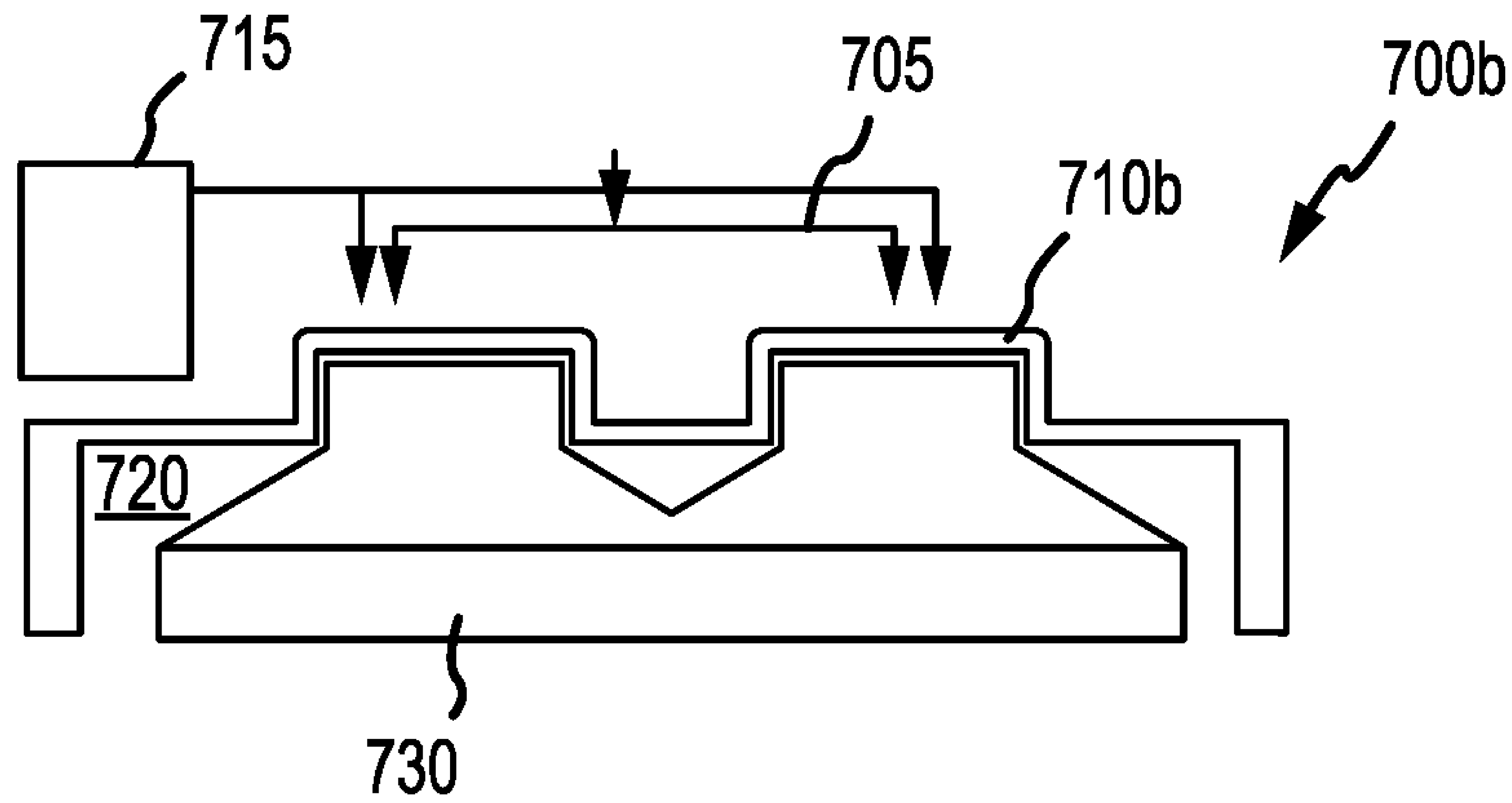


*FIG. 7B*

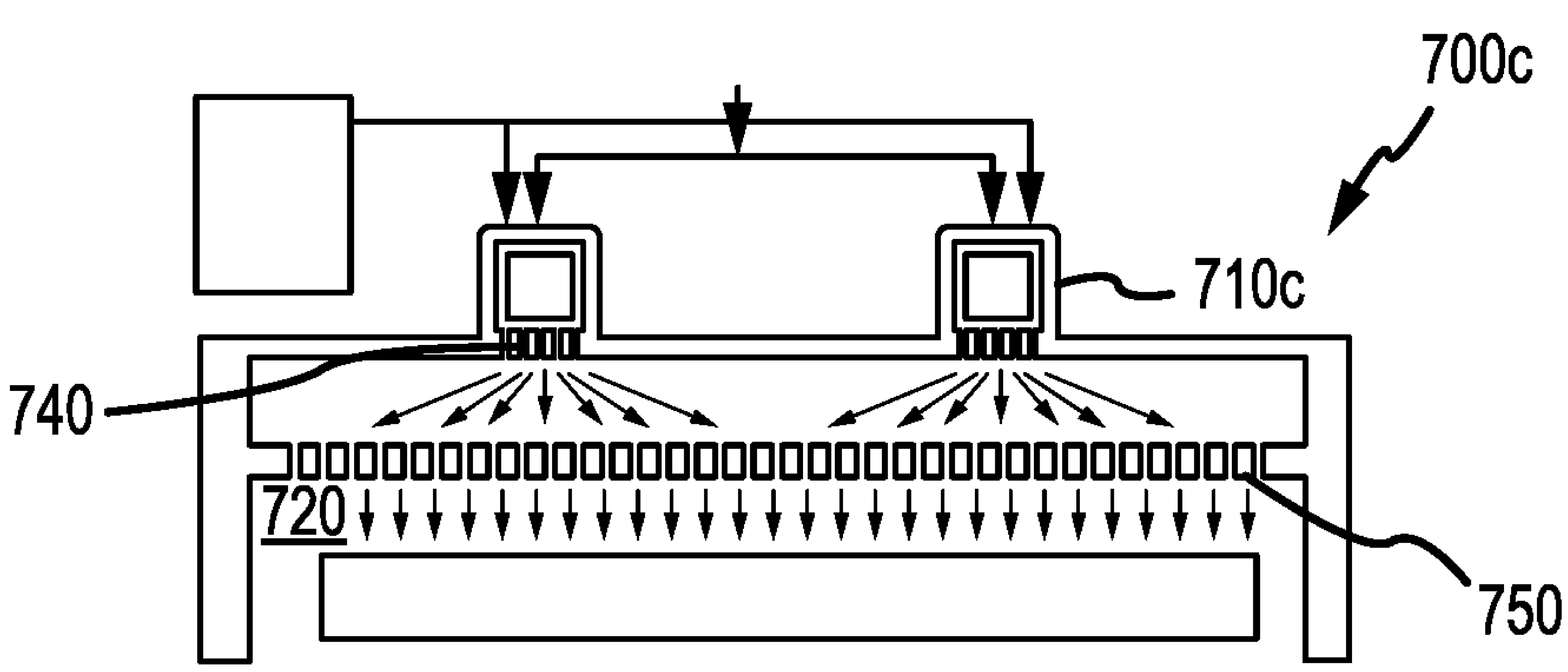


*FIG. 7C*

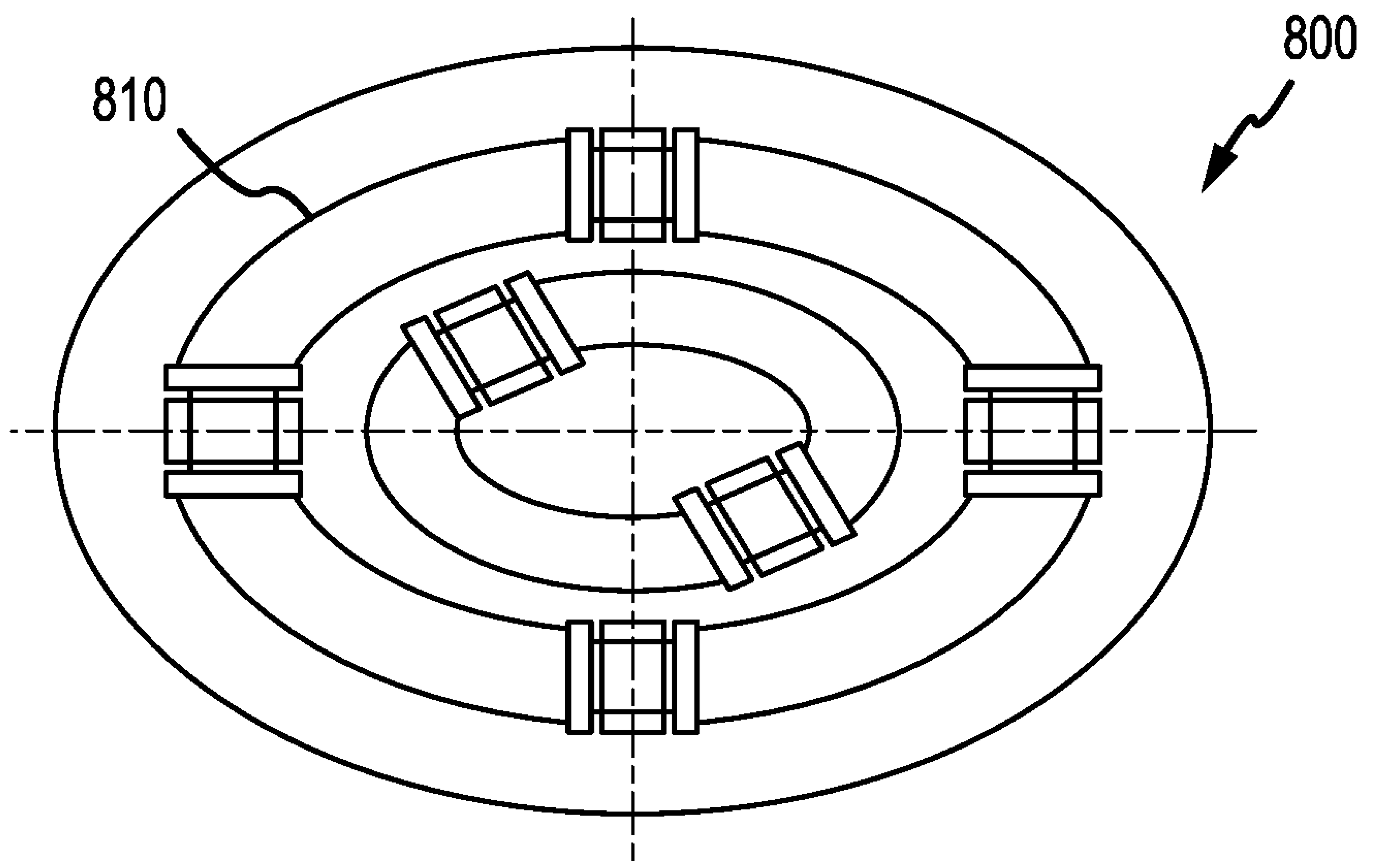


FIG.8A

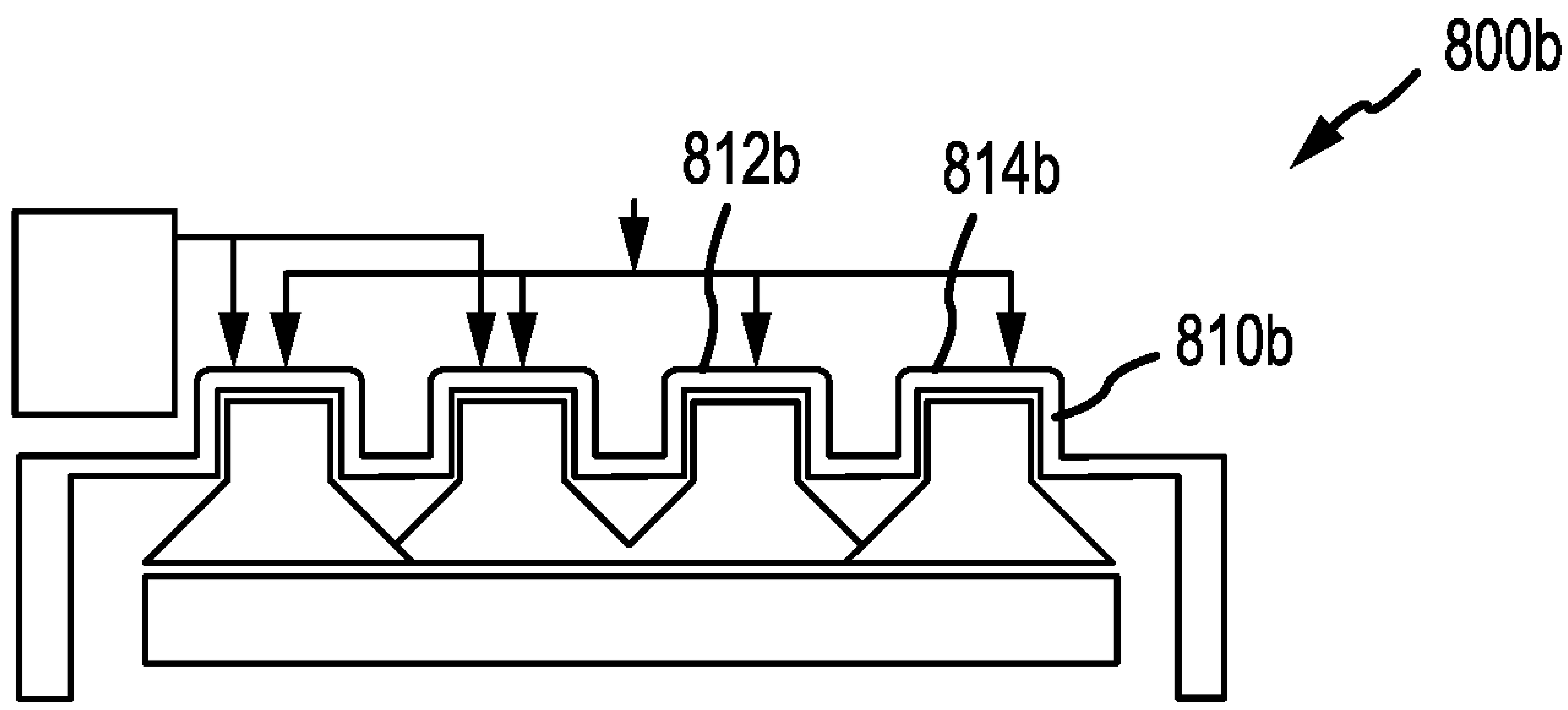


FIG.8B

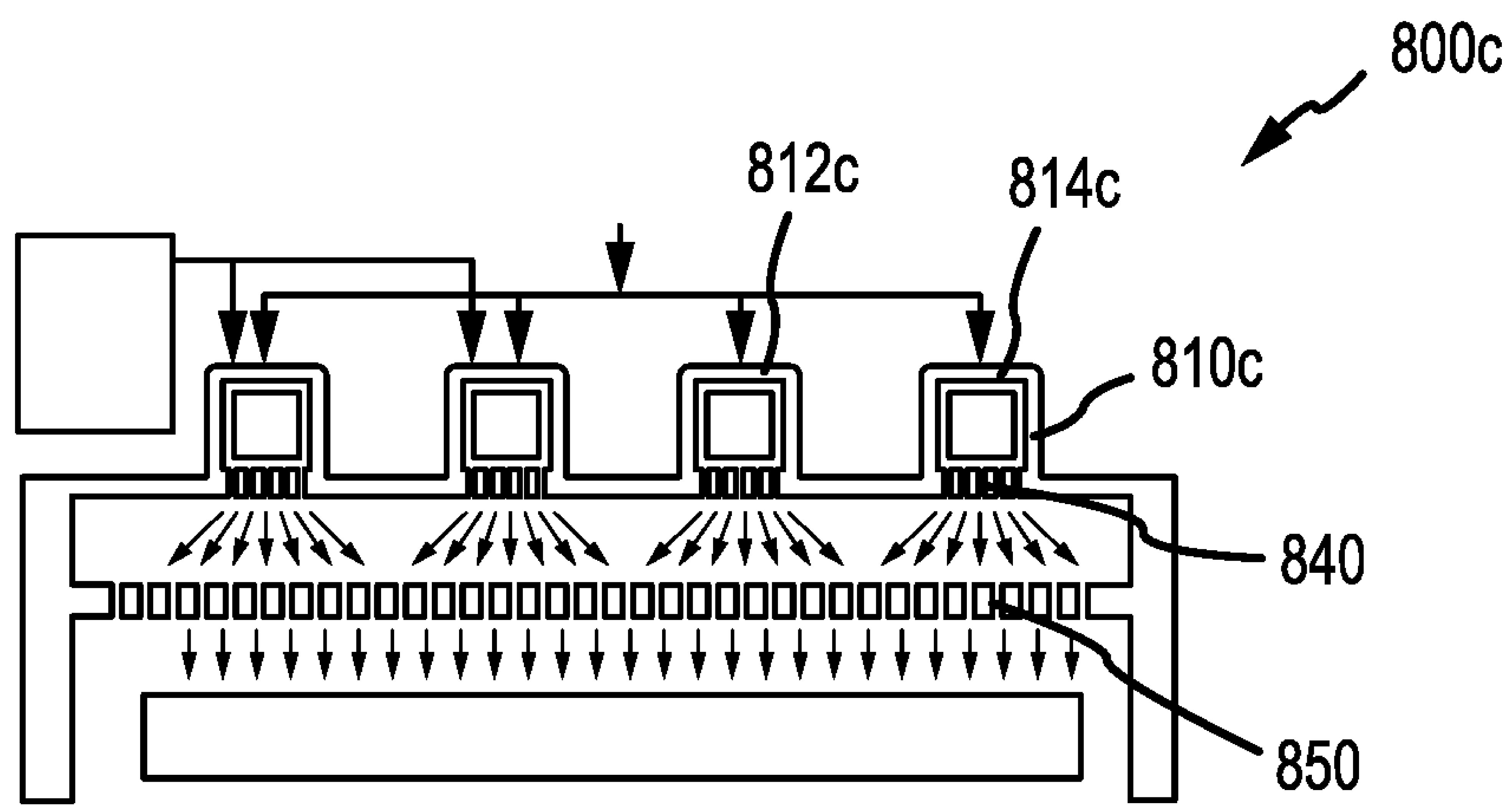


FIG.8C

# MAGNETIC INDUCTION PLASMA SOURCE FOR SEMICONDUCTOR PROCESSES AND EQUIPMENT

## TECHNICAL FIELD

The present technology relates to semiconductor processes and equipment. More specifically, the present technology relates to magnetic induction plasma sources for semiconductor processes and equipment.

## BACKGROUND

Integrated circuits are made possible by processes which produce intricately patterned material layers on substrate surfaces. Producing patterned material on a substrate requires controlled methods for removal of exposed material. Chemical etching is used for a variety of purposes including transferring a pattern in photoresist into underlying layers, thinning layers, or thinning lateral dimensions of features already present on the surface. Often it is desirable to have an etch process that etches one material faster than another, facilitating, for example, a pattern transfer process. Such an etch process is said to be selective to the first material. As a result of the diversity of materials, circuits, and processes, etch processes have been developed with a selectivity towards a variety of materials.

Etch processes may be termed wet or dry based on the materials used in the process. A wet HF etch preferentially removes silicon oxide over other dielectrics and materials. However, wet processes may have difficulty penetrating some constrained trenches and also may sometimes deform the remaining material. Dry etches produced in local plasmas formed within the substrate processing region can penetrate more constrained trenches and exhibit less deformation of delicate remaining structures. However, local plasmas may damage the substrate through the production of electric arcs as they discharge.

Thus, there is a need for improved systems and methods that can be used to produce high quality devices and structures. These and other needs are addressed by the present technology.

## SUMMARY

Exemplary systems for generating plasma products may include magnetic induction plasma systems. The magnetic induction plasma system may include a first plasma source. The first plasma source may include one or more first sections and one or more second sections. The one or more first sections and the one or more second sections may be fluidly coupled with each other such that at least a portion of plasma products generated inside the first plasma source may circulate through at least one of the one or more first sections. At least a portion of the plasma products generated inside the second plasma source may also circulate through at least one of the one or more second sections inside the first plasma source. Each of the one or more second sections may include a dielectric material. The one or more first sections and the one or more second sections may be arranged in an alternating manner such that the one or more first sections may be electrically insulated from each other at least in part by the one or more second sections.

In some embodiments, the magnetic plasma induction system may further include one or more first magnetic elements. Each of the one or more first magnetic elements may define a closed loop and may be positioned around one



of the one or more second sections. The first plasma source may define a first toroidal shape. The first toroidal shape may include a first toroidal extension and a first toroidal axis perpendicular to the first toroidal extension. Each of the one or more first sections may include a first dimension parallel to the first toroidal axis. Each of the one or more second sections may include a second dimension parallel to the first toroidal axis. The first dimension may be greater than the second dimension such that the one or more second sections may define one or more recesses. Each of the one or more recesses may be configured to receive at least a portion of one of the one or more first magnetic elements.

In some embodiments, each of the one or more first sections may include a first opening and a second opening. Each of the one or more first sections and the corresponding first and second openings may define a flow passage parallel to the first toroidal axis such that a precursor for generating the plasma products inside the first plasma source may be flowed into each first section through the first opening and at least a portion of the plasma products generated may be flowed out of each first section through the second opening.

In some embodiments, the magnetic induction plasma system may further include one or more first dielectric ring members and one or more second dielectric ring members. The one or more first dielectric ring members may be positioned above the first openings, and the one or more second dielectric ring members may be positioned below the second openings such that the one or more first sections may be electrically insulated from each other when the magnetic induction plasma system may be integrated into a semiconductor processing chamber and may be positioned between metal components of the semiconductor processing chamber along the first toroidal axis.

In some embodiments, the semiconductor processing chamber may include a gas inlet assembly and a gas distribution assembly. The gas inlet assembly may be positioned upstream of the magnetic induction plasma system. The gas distribution assembly may be positioned downstream of the magnetic induction plasma system. The one or more first dielectric ring members may define a first planar supporting surface and may be configured to support the gas inlet assembly. The one or more second dielectric ring members may define a second planar supporting surface and may be configured to be supported by the gas distribution assembly.

In some embodiments, each of the one or more first sections may include an arcuate tubular body. In some embodiments, each of the one or more second sections may include a pair of flanges configured at two opposite ends of each second section and may be configured to couple each second section with two adjacent first sections. In some embodiments, each of the one or more first sections may include a first extension along the first toroidal extension. Each of the one or more second sections may include a second extension along the first toroidal extension. A ratio of the first extension to the second extension may be between about 10:1 and about 2:1 such that circulation of at least a portion of plasma products inside the first plasma source may be facilitated.

In some embodiments, the magnetic induction plasma system may further include a second plasma source. The second plasma source may define a second toroidal shape. The second toroidal shape may include a second toroidal extension and a second toroidal axis perpendicular to the second toroidal extension. The second toroidal axis may be aligned with the first toroidal axis. The second plasma source may be positioned radially inward from the first plasma source. The second plasma source may include a third section and a fourth section. At least one of the third section or the fourth section may include a dielectric material. The second plasma source may further include at least one second magnetic element. The at least one second magnetic element may define a closed loop and may be positioned around at least one of the third section or the fourth section. In some embodiments, the at least one second magnetic element may be positioned at an azimuthal angle different from an azimuthal angle of each of the one or more first magnetic elements such that interference between an electric field generated by each of the one or more first magnetic elements and an electric field generated by the at least one second magnetic element may be reduced.

In some embodiments, the first plasma source and the second plasma source may be configured such that the plasma products exiting the first plasma source may diffuse onto a first region of a substrate, and the plasma products exiting the second plasma source may diffuse onto a second region of the substrate. The first region may define a substantially annular shape. The second region may define a substantially circular shape. The first region and the second region may overlap.

In some embodiments, the magnetic induction plasma system may further include one or more electrically coupled first coils and a second coil. Each of the one or more electrically coupled first coils may be configured around at least a portion of each of the one or more first magnetic elements. The second coil may be configured around at least a portion of the at least one second magnetic element. The magnetic induction plasma system may be driven by an LLC resonant half bridge circuit. The LLC resonant half bridge circuit may be configured to supply a first current to the one or more electrically coupled first coils at a first frequency. The LLC resonant half bridge circuit may be configured to supply a second current to the second coil at a second frequency. The first frequency may match the second frequency. In some embodiments, the LLC resonant half bridge circuit may be configured to supply the first current and the second current at a frequency between about 100 kHz and about 20 MHz. In some embodiments, the LLC resonant half bridge circuit may be configured to supply a first power to the one or more electrically coupled first coils and to supply a second power to the second coil. The first power may be greater than the second power.

The present technology may also include methods of generating plasma products. The methods may include flowing a precursor into a plasma source. The methods may further include forming a plasma from the precursor to produce plasma products. The plasma source may define a first toroidal shape. The first toroidal shape may include a first toroidal extension and a first toroidal axis perpendicular to the first toroidal extension. The plasma source may include one or more first sections and one or more second sections. The one or more first sections and the one or more second sections may be fluidly coupled with each other along the first toroidal extension such that a first portion of the plasma products may circulate through at least one of the one or more first sections substantially along the first toroidal extension inside the plasma source. The first portion of the plasma products may further circulate through at least one of the one or more second sections substantially along the first toroidal extension inside the plasma source. Each of the one or more second sections may include a dielectric material. The one or more first sections and the one or more second sections may be arranged in an alternating manner such that the one or more first sections may be electrically insulated from each other at least in part by the one or more second sections.

In some embodiments, the plasma source may further include one or more first magnetic elements. Each of the one or more first magnetic elements may define a closed loop and may be positioned around one of the one or more second sections. Each of the one or more first sections may include a first dimension parallel to the first toroidal axis. Each of the one or more second sections may include a second dimension parallel to the first toroidal axis. The first dimension may be greater than the second dimension such that the one or more second sections may define one or more recesses. Each of the one or more recesses may be configured to receive at least a portion of one of the one or more first magnetic elements.

In some embodiments, the method for generating plasma products may further include maintaining a pressure within the plasma source between about 1 mTorr and about 500 Torr. In some embodiments, the plasma source may further include one or more electrically coupled coils. Each of the one or more electrically coupled coils may be configured around at least a portion of each of the one or more first magnetic elements. In some embodiments, the method may further include supplying a current to the one or more electrically coupled coils by an LLC resonant half bridge circuit at a frequency between about 100 kHz and about 20 MHz. In some embodiments, the method may further include supplying a power between about 100 W and about 1,000 W by the LLC resonant half bridge circuit to the one or more electrically coupled coils for generating products from the precursor inside the plasma source.

The present technology may also include a semiconductor processing chamber including a magnetic induction plasma system. The magnetic induction plasma system may include a first plasma source having a first toroidal shape. The first plasma source may define a first annular recess of the first toroidal shape. The magnetic induction plasma system may further include a first magnetic element. The first magnetic element may form a closed loop and may be positioned around a portion of the first plasma source. At least a portion of the first magnetic element may be received within the first annular recess. In some embodiments, the first plasma source may include a first inlet for a precursor for generating plasma products therefrom inside the first plasma source. The first plasma source may further include a first outlet for the plasma products generated. The first inlet, the first outlet, and the first plasma source may include a common width dimension measured along a radial direction of the first toroidal shape.

In some embodiments, the magnetic induction plasma system may further include a second plasma source having a second toroidal shape. The second plasma source and the first plasma source may have a common toroidal axis. The second plasma source may be positioned radially inward from the first plasma source. The second plasma source may define a second annular recess of the second toroidal shape. The magnetic induction plasma system may further include a second magnetic element. The second magnetic element may form a closed loop and may be positioned around a portion of the second plasma source. At least a portion of the second magnetic element may be received within the second annular recess. The second plasma source may include a second inlet for the precursor for generating plasma products therefrom inside the second plasma source and a second outlet for the plasma products generated. The second inlet, the second outlet, and the second plasma source may have a common width dimension measured along a radial direction of the second toroidal shape. The first magnetic element may be positioned at a first azimuthal angle. The second magnetic element may be positioned at a second azimuthal angle. The first azimuthal angle may be different from the second azimuthal angle.

Such technology may provide numerous benefits over conventional systems and techniques. For example, the magnetic induction plasma systems described herein may allow for low driving power, and may yield high power transfer efficiency. Additionally, the driving power, frequency, and current may be fully adjustable to allow for modulation of the composition and property of the plasma generated. Moreover, the magnetic induction plasma systems may operate to generate a plasma at a wide operational pressure ranging from several tens of mTorr to several hundred Torr. These and other embodiments, along with many of their advantages and features, are described in more detail in conjunction with the below description and attached figures.

## BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the nature and advantages of the disclosed technology may be realized by reference to the remaining portions of the specification and the drawings.

FIG. **1** shows a top plan view of one embodiment of an exemplary processing system according to embodiments of the present technology.

FIG. **2**A shows a schematic cross-sectional view of an exemplary processing chamber according to embodiments of the present technology.

FIG. **2**B shows a detailed view of a portion of the processing chamber illustrated in FIG. **2**A according to embodiments of the present technology.

FIG. **3** shows schematic views of exemplary showerhead configurations according to embodiments of the present technology.

FIGS. **4**A-**4**F show schematic views of an exemplary plasma system according to embodiments of the present technology.

FIGS. **5**A-**5**C show schematic views of an exemplary plasma system according to embodiments of the present technology.

FIGS. **6**A-**6**C show schematic views of an exemplary plasma system according to embodiments of the present technology.

FIGS. **7**A-**7**C show schematic views of an exemplary plasma system in operation according to embodiments of the present technology.

FIGS. **8**A-**8**C show schematic views of an exemplary plasma system in operation according to embodiments of the present technology.

Several of the figures are included as schematics. It is to be understood that the figures are for illustrative purposes, and are not to be considered of scale unless specifically stated to be of scale. Additionally, as schematics, the figures are provided to aid comprehension and may not include all aspects or information compared to realistic representations, and may include exaggerated material for illustrative purposes.

In the appended figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a letter that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the letter.

## DETAILED DESCRIPTION

Conventional plasma generating systems may typically utilize a full bridge circuit driving scheme, which can consume a large amount of power due to power loss in the driving circuitry and can be very costly to operate. Additionally, conventional plasma generating systems driven by a full bridge circuit may generally require high power of 10,000 W or higher to generate and sustain a plasma.

The various embodiments of the magnetic induction plasma systems described herein may utilize a particularly configured LLC resonant half bridge circuit driving scheme. The LLC resonant half bridge circuit may generally be more reliable and cost effective as compared to the conventional full bridge circuit for plasma generation. The LLC resonant half bridge circuit may also yield higher power transfer efficiency, as compared to a conventional plasma generating system using a full bridge circuit driving scheme. In a conventional plasma generating system using a full bridge circuit driving scheme, energy loss on the driving circuit may be significant. The magnetic induction plasma systems described herein may yield greater energy transfer efficiency from the power source to the plasma given that the LLC resonant half bridge circuit driving scheme may require significantly lower power to ignite and/or sustain the plasma while yielding similar dissociation of the precursor gases. Further, the magnetic induction plasma systems described herein may allow for power adjustment from 0 W to about 1,000 W or higher. By adjusting the power output, the dissociation rate of the precursor gases may be modulated to achieve a desired composition of the plasma products. The magnetic induction plasma systems described herein may further allow for a wide operational frequency range from several ten kHz to several dozen MHz or more, and a wide operational pressure range from dozens of mTorr to several hundred Torr or more, under which a stable plasma may be generated and sustained.

FIG. **1** shows a top plan view of one embodiment of a processing system **100** of deposition, etching, baking, and curing chambers according to embodiments. In the figure, a pair of front opening unified pods (FOUPs) **102** supply substrates of a variety of sizes that are received by robotic arms **104** and placed into a low pressure holding area **106** before being placed into one of the substrate processing chambers **108***a-f*, positioned in tandem sections **109***a-c*. A second robotic arm **110** may be used to transport the substrate wafers from the holding area **106** to the substrate processing chambers **108***a-f* and back. Each substrate processing chamber **108***a-f*, can be outfitted to perform a number of substrate processing operations including the dry etch processes described herein in addition to cyclical layer deposition (CLD), atomic layer deposition (ALD), chemical vapor deposition (CVD), physical vapor deposition (PVD), etch, pre-clean, degas, orientation, and other substrate processes.

The substrate processing chambers **108***a-f* may include one or more system components for depositing, annealing, curing and/or etching a dielectric or metallic film on the substrate wafer. In one configuration, two pairs of the processing chambers, e.g., **108***c-d* and **108***e-f*, may be used to deposit material on the substrate, and the third pair of processing chambers, e.g., **108***a-b*, may be used to etch the deposited material. In another configuration, all three pairs of chambers, e.g., **108***a-f*, may be configured to etch a dielectric or metallic film on the substrate. Any one or more of the processes described may be carried out in chamber(s) separated from the fabrication system shown in different embodiments. It will be appreciated that additional configurations of deposition, etching, annealing, and curing chambers for dielectric films are contemplated by system **100**.

FIG. **2**A shows a cross-sectional view of an exemplary process chamber system **200** with partitioned plasma generation regions within the processing chamber. During film etching, e.g., titanium nitride, tantalum nitride, tungsten, copper, cobalt, silicon, polysilicon, silicon oxide, silicon nitride, silicon oxynitride, silicon oxycarbide, etc., a process gas may be flowed into the first plasma region **215** through a gas inlet assembly **205**. A remote plasma system (RPS) **201** may optionally be included in the system, and may process a first gas which then travels through gas inlet assembly **205**. The inlet assembly **205** may include two or more distinct gas supply channels where the second channel (not shown) may bypass the RPS **201**, if included.

A cooling plate **203**, faceplate **217**, ion suppressor **223**, showerhead **225**, and a substrate support **265**, having a substrate **255** disposed thereon, are shown and may each be included according to embodiments. The pedestal **265** may have a heat exchange channel through which a heat exchange fluid flows to control the temperature of the substrate, which may be operated to heat and/or cool the substrate or wafer during processing operations. The wafer support platter of the pedestal **265**, which may comprise aluminum, ceramic, or a combination thereof, may also be resistively heated in order to achieve relatively high temperatures, such as from up to or about 100° C. to above or about 600° C., using an embedded resistive heater element.

The faceplate **217** may be pyramidal, conical, or of another similar structure with a narrow top portion expanding to a wide bottom portion. The faceplate **217** may additionally be flat as shown and include a plurality of through-channels used to distribute process gases. Plasma generating gases and/or plasma excited species, depending on use of the RPS **201**, may pass through a plurality of holes, shown in FIG. **2**B, in faceplate **217** for a more uniform delivery into the first plasma region **215**.

Exemplary configurations may include having the gas inlet assembly **205** open into a gas supply region **258** partitioned from the first plasma region **215** by faceplate **217** so that the gases/species flow through the holes in the faceplate **217** into the first plasma region **215**. Structural and operational features may be selected to prevent significant backflow of plasma from the first plasma region **215** back into the supply region **258**, gas inlet assembly **205**, and fluid supply system **210**. The faceplate **217**, or a conductive top portion of the chamber, and showerhead **225** are shown with an insulating ring **220** located between the features, which allows an AC potential to be applied to the faceplate **217** relative to showerhead **225** and/or ion suppressor **223**. The insulating ring **220** may be positioned between the faceplate **217** and the showerhead **225** and/or ion suppressor **223** enabling a capacitively coupled plasma (CCP) to be formed in the first plasma region. A baffle (not shown) may additionally be located in the first plasma region **215**, or otherwise coupled with gas inlet assembly **205**, to affect the flow of fluid into the region through gas inlet assembly **205**.

The ion suppressor **223** may comprise a plate or other geometry that defines a plurality of apertures throughout the structure that are configured to suppress the migration of ionically-charged species out of the first plasma region **215** while allowing uncharged neutral or radical species to pass through the ion suppressor **223** into an activated gas delivery region between the suppressor and the showerhead. In embodiments, the ion suppressor **223** may comprise a perforated plate with a variety of aperture configurations. These uncharged species may include highly reactive species that are transported with less reactive carrier gas through the apertures. As noted above, the migration of ionic species through the holes may be reduced, and in some instances completely suppressed. Controlling the amount of ionic species passing through the ion suppressor **223** may advantageously provide increased control over the gas mixture brought into contact with the underlying wafer substrate, which in turn may increase control of the deposition and/or etch characteristics of the gas mixture. For example, adjustments in the ion concentration of the gas mixture can significantly alter its etch selectivity, e.g., SiNx:SiOx etch ratios, Si:SiOx etch ratios, etc. In alternative embodiments in which deposition is performed, it can also shift the balance of conformal-to-flowable style depositions for dielectric materials.



The plurality of apertures in the ion suppressor **223** may be configured to control the passage of the activated gas, i.e., the ionic, radical, and/or neutral species, through the ion suppressor **223**. For example, the aspect ratio of the holes, or the hole diameter to length, and/or the geometry of the holes may be controlled so that the flow of ionically-charged species in the activated gas passing through the ion suppressor **223** is reduced. The holes in the ion suppressor **223** may include a tapered portion that faces the plasma excitation region **215**, and a cylindrical portion that faces the showerhead **225**. The cylindrical portion may be shaped and dimensioned to control the flow of ionic species passing to the showerhead **225**. An adjustable electrical bias may also be applied to the ion suppressor **223** as an additional means to control the flow of ionic species through the suppressor.

The ion suppressor **223** may function to reduce or eliminate the amount of ionically charged species traveling from the plasma generation region to the substrate. Uncharged neutral and radical species may still pass through the openings in the ion suppressor to react with the substrate. It should be noted that the complete elimination of ionically charged species in the reaction region surrounding the substrate may not be performed in embodiments. In certain instances, ionic species are intended to reach the substrate in order to perform the etch and/or deposition process. In these instances, the ion suppressor may help to control the concentration of ionic species in the reaction region at a level that assists the process.

Showerhead **225** in combination with ion suppressor **223** may allow a plasma present in first plasma region **215** to avoid directly exciting gases in substrate processing region **233**, while still allowing excited species to travel from chamber plasma region **215** into substrate processing region **233**. In this way, the chamber may be configured to prevent the plasma from contacting a substrate **255** being etched. This may advantageously protect a variety of intricate structures and films patterned on the substrate, which may be damaged, dislocated, or otherwise warped if directly contacted by a generated plasma. Additionally, when plasma is allowed to contact the substrate or approach the substrate level, the rate at which oxide species etch may increase. Accordingly, if an exposed region of material is oxide, this material may be further protected by maintaining the plasma remotely from the substrate.

The processing system may further include a power supply **240** electrically coupled with the processing chamber to provide electric power to the faceplate **217**, ion suppressor **223**, showerhead **225**, and/or pedestal **265** to generate a plasma in the first plasma region **215** or processing region **233**. The power supply may be configured to deliver an adjustable amount of power to the chamber depending on the process performed. Such a configuration may allow for a tunable plasma to be used in the processes being performed. Unlike a remote plasma unit, which is often presented with on or off functionality, a tunable plasma may be configured to deliver a specific amount of power to the plasma region **215**. This in turn may allow development of particular plasma characteristics such that precursors may be dissociated in specific ways to enhance the etching profiles produced by these precursors.

A plasma may be ignited either in chamber plasma region **215** above showerhead **225** or substrate processing region **233** below showerhead **225**. Plasma may be present in chamber plasma region **215** to produce the radical precursors from an inflow of, for example, a fluorine-containing precursor or other precursor. An AC voltage typically in the radio frequency (RF) range may be applied between the conductive top portion of the processing chamber, such as faceplate **217**, and showerhead **225** and/or ion suppressor **223** to ignite a plasma in chamber plasma region **215** during deposition. An RF power supply may generate a high RF frequency of 13.56 MHz but may also generate other frequencies alone or in combination with the 13.56 MHz frequency.

FIG. **2**B shows a detailed view **253** of the features affecting the processing gas distribution through faceplate **217**. As shown in FIGS. **2**A and **2**B, faceplate **217**, cooling plate **203**, and gas inlet assembly **205** intersect to define a gas supply region **258** into which process gases may be delivered from gas inlet **205**. The gases may fill the gas supply region **258** and flow to first plasma region **215** through apertures **259** in faceplate **217**. The apertures **259** may be configured to direct flow in a substantially unidirectional manner such that process gases may flow into processing region **233**, but may be partially or fully prevented from backflow into the gas supply region **258** after traversing the faceplate **217**.

The gas distribution assemblies such as showerhead **225** for use in the processing chamber section **200** may be referred to as dual channel showerheads (DCSH) and are additionally detailed in the embodiments described in FIG. **3**. The dual channel showerhead may provide for etching processes that allow for separation of etchants outside of the processing region **233** to provide limited interaction with chamber components and each other prior to being delivered into the processing region.

The showerhead **225** may comprise an upper plate **214** and a lower plate **216**. The plates may be coupled with one another to define a volume **218** between the plates. The coupling of the plates may be so as to provide first fluid channels **219** through the upper and lower plates, and second fluid channels **221** through the lower plate **216**. The formed channels may be configured to provide fluid access from the volume **218** through the lower plate **216** via second fluid channels **221** alone, and the first fluid channels **219** may be fluidly isolated from the volume **218** between the plates and the second fluid channels **221**. The volume **218** may be fluidly accessible through a side of the gas distribution assembly **225**.

FIG. **3** is a bottom view of a showerhead **325** for use with a processing chamber according to embodiments. Showerhead **325** may correspond with the showerhead **225** shown in FIG. **2**A. Through-holes **365**, which show a view of first fluid channels **219**, may have a plurality of shapes and configurations in order to control and affect the flow of precursors through the showerhead **225**. Small holes **375**, which show a view of second fluid channels **221**, may be distributed substantially evenly over the surface of the showerhead, even amongst the through-holes **365**, and may help to provide more even mixing of the precursors as they exit the showerhead than other configurations.

FIGS. **4**A-**4**C illustrate schematic top plan views of one embodiment of a magnetic induction plasma system **400** which may be used or integrated in the processing chamber **200** described above. FIG. **4**A illustrates the magnetic induction plasma system **400** before a plasma may be generated or ignited; FIG. **4**B illustrates the magnetic induction plasma system **400** during plasma ignition; and FIG. **4**C illustrates the magnetic induction plasma system **400** when a plasma may be sustained by the magnetic induction plasma system **400**. With reference to FIG. **4**A, the magnetic induction plasma system **400** may include a plasma source or discharge tube **410** characterized by an annular cross-section, and one or more magnetic elements **420***a*, **420***b*, **420***c*, **420***d* positioned around the plasma source **410**. The plasma source **410** may be characterized by an annular shape, and may be characterized by a substantially toroidal shape having a toroidal axis **1** (shown as a dot in FIG. **4**A) at the center of the toroidal shape and extending normal to the plane shown as FIG. **4**A. As also shown in FIG. **4**A, additional useful references for ease of description may include a radial direction **2** perpendicular to the toroidal axis **1**, denoting a direction extending radially outward from a central axis of the plasma source **410**, and an azimuthal direction **3**, denoting a rotational direction about the toroidal axis **1**. A toroidal extension or toroidal direction **4** may be defined as the extension or direction of the plasma source **410** along which a plasma current may be formed inside the plasma source **410** (as will be described in more detail below).

As shown in FIGS. **4**D-**4**F, which schematically illustrate side views of the magnetic element **420** before plasma ignition, during plasma ignition, and during plasma maintenance, respectively. The magnetic elements **420** may each form a closed loop. The magnetic element **420** may define a hollow center **422** through which a portion of the plasma source **410** may extend therethrough. The magnetic element **420** may include a magnetic body **424** that may define the closed loop. The magnetic body **424** may be formed of ferrite or other magnetizable materials. As also shown in FIGS. **4**D-**4**F, the magnetic induction plasma system **400** may further include a coil **430** (not shown in FIGS. **4**A-**4**C) wrapped around at least a portion of the magnetic body **424** of each magnetic element **420**. Electrical energy may be supplied to each coil **430** for generating a plasma inside the plasma source **410**. Specifically, the electrical energy supplied to the coils **430** may generate a magnetic field inside each magnetic element **420**, which may in turn induce an electric field E as shown in FIGS. **4**A and **4**D.

The plasma source **410** may be formed of non-conductive materials or materials with very low or little conductivity, such as dielectric materials, including, but not limited to, ceramic, quartz, sapphire, etc. In some embodiments, the plasma source **410** may be formed of conductive materials, such as metals, including, but not limited to, aluminum, stainless steel, etc., and the magnetic induction plasma system **400** may further include one or more dielectric sections or dielectric breaks **440** forming a section or sections of the plasma source **410**. With either configuration, the plasma source **410** may not form a closed conductive body, and the induced electric field E may increase to a threshold value to ignite or ionize a gas or gas mixture that may be supplied into the plasma source **410**, as shown in

FIGS. **4**B and **4**E, to form a plasma. Once the plasma may be ignited, at least a portion of the ionized or charged plasma products may circulate inside the plasma source **410** forming a close-looped current **450**, as shown in FIGS. **4**C and **4**F. The coils **430** and the plasma current **450** may then operate in a manner similar to how a primary coil and a secondary coil of a transformer may operate. As electrical energy may be supplied to the coils **430** continuously, the supplied electric energy may be transferred to the plasma current **450**, and a stable plasma may be sustained.

With reference to FIG. **4**D, the magnetic body **424** may include an outer surface **426** and an inner surface **428** each of which may include a square shaped cross section. In some embodiments, the outer surface **426** and the inner surface **428** may include other polygonal shaped cross sections, circular, or oval cross sections, etc. Magnetic bodies **424** with circular or oval cross sections may contain substantially all the magnetic flux generated inside the magnetic body **424** and limit or prevent leakage flux, thereby improving the efficiency of the magnetic induction plasma system **400**, whereas the magnetic flux generated by the coils **430** may escape or leak at the corners of the magnetic bodies **424** with polygonal cross sections. Nevertheless, the magnetic bodies **424** forming closed loops may generally offer higher efficiency for the magnetic induction plasma system **400** as compared to open magnetic bodies that do not form closed loops because magnetic flux may not form a closed loop and may escape without inducing an electrical field for generating plasma.

Although not shown in FIGS. **4**A-**4**F, the plasma source **410** may include cross-sectional shapes similar to or different from those of the magnetic element **420**. In some embodiments, the plasma source **410** may include inner and outer surfaces that may include square or other polygonal cross sections. In some embodiments, the plasma source **410** may include inner and outer surfaces that may include circular or oval cross sections, and the plasma source **410** may be formed as a circular tube.

The magnetic elements **420** may be positioned around the plasma source **410** at various locations or azimuthal angles. FIGS. **4**A-**4**C illustrate that the magnetic induction plasma system **400** may include four magnetic elements **420**. The magnetic induction plasma system **400** may include more or less than four magnetic elements **420**, but may include at least one magnetic element **420**. The magnetic elements **420** may be positioned along the toroidal extension of the plasma source **410** at an equal distance from each other such that the azimuthal angle between any two adjacent magnetic elements **420** may be the same. For example, in the embodiment shown in FIGS. **4**A-**4**C, the magnetic induction plasma system **400** may include four magnetic elements **420**, and any two adjacent magnetic elements **420** may be positioned apart from each other by an azimuthal angle of about 90 degrees or by a distance of about a quarter of the toroidal extension of the plasma source **410**.

Depending on the number of magnetic elements **420** the magnetic induction plasma system **400** may include, the azimuthal angle between any two adjacent magnetic elements **420** may be greater or less than 90 degrees, and the distance between any two adjacent magnetic elements **420** may be greater or less than a quarter of the toroidal extension of the plasma source **410**. Although FIGS. **4**A-**4**C illustrates that the magnetic elements **420** may be spaced apart at an equal distance or equal azimuthal angle, in some embodiments, the magnetic elements **420** may be spaced apart at a non-equal distance or non-equal azimuthal angle. In other words, the distance between two adjacent magnetic elements **420** along the toroidal extension of the plasma source **410** or the azimuthal angle between the two adjacent magnetic elements **420** may be different from the distance or azimuthal angle between another two adjacent magnetic elements **420**. However, positioning the magnetic elements **420** at an equal distance or azimuthal angle may improve the uniformity of the plasma products generated inside the plasma source **410**. Accordingly, in some embodiments, regardless of the number of magnetic elements **420** included, the magnetic elements may be equidistantly spaced about the plasma source **410**.

Although only one dielectric section **440** is shown in FIGS. **4**A-**4**C, the magnetic induction plasma system **400** may include more than one dielectric section **440**. In some embodiments, the magnetic induction plasma system **400** may include the same number of dielectric sections **440** as magnetic elements **420**. The multiple dielectric sections **440** may be positioned at an equal distance or non-equal distances along the toroidal extension of the plasma source **410**. In some embodiments, the magnetic induction plasma system **400** may include more dielectric sections **440** than magnetic elements **420**. In the embodiment shown in FIGS. **4**A-**4**C, each of the magnetic elements **420** may be positioned at a different azimuthal angle from the dielectric section **440**. In some embodiments, at least one of the magnetic elements **420** may be positioned at the same azimuthal angle, or aligned, with the dielectric section **440**. In the embodiments where the magnetic induction plasma system **400** may include an equal number of magnetic elements **420** and dielectric sections **440**, each magnetic element **420** may be aligned with a dielectric section **440**.

FIG. **5**A schematically illustrates a perspective view of an embodiment of a magnetic induction plasma system **500** which may be used or integrated in the processing chamber **200** described above. The magnetic induction plasma system **500** may include a plasma source **510** defining a substantially toroidal shape. Although not shown in FIG. **5**A, similar references including toroidal axis, radial direction, azimuthal direction, and toroidal extension or direction as shown in FIG. **4**A, may be used for description of the embodiment shown in FIG. **5**A. Different from the plasma source **410** shown in FIGS. **4**A-**4**C, which may include a uniform or consistent width dimension along the toroidal extension with the width dimension being measured along the radial direction and a uniform and consistent height dimension measured parallel to the toroidal axis, the plasma source **510** may include varying width dimensions and/or varying height dimensions along the toroidal extension. Specifically, the plasma source **510** may include one or more first sections **515** which may be or include metal sections and one or more second sections **540** which may be or may include dielectric sections or dielectric breaks. The first sections **515** and the second sections **540** may be arranged in an alternating manner such that the first sections **515** may be electrically isolated or insulated from each other by the second sections **540**. The first sections **515** and the second sections **540** may include different width and height dimensions from each other.

As shown in FIG. **5**A, the first sections **515** may each include a first width dimension, and the second sections **540** may each include a second width dimension that may be less than the first width dimension. The first sections **515** may each further include a first height dimension, and the second section **540** may each further include a second height dimension that may be less than the first height dimension. Accordingly, the second sections **540** may define one or more annular recesses, each of which may be configured to receive therein at least a portion of a magnetic element **520**, as shown in FIG. **5**B, which illustrates a cross sectional view of the second section **540** viewed along line **5**B-**5**B of FIG. **5**A. Each second section **540** may further include a pair of flanges **542***a*, **542***b* (shown in FIG. **5**A) at opposite ends of each second section **540**. The flanges **542** may be configured to couple each second section **540** with two adjacent first sections **515**. For example, each of the first sections **515** may be configured with inward lips or flanges at the opposite ends. The flanges **542** of the second sections **540** and the inward lips or flanges of the first sections **515** may be coupled with each other via bolts, screws, glue, adhesive, welding, brazing, and any suitable bonding or coupling mechanism.

As shown in FIGS. **5**A and **5**B, the second sections **540** may each be formed as a cylindrical body. The magnetic elements **520** may also each be formed as a cylindrical body, which may be positioned concentrically with the second section **540**. In some embodiments, the second sections **540** and/or the magnetic elements **520** may be formed with cross-sectional shapes that may be polygonal. As discussed above, circular or oval shaped magnetic elements **520** may limit magnetic flux leakage, thereby improving the efficiency of the magnetic induction plasma system **500**. Accordingly, the magnetic elements may be characterized by elliptical cross-sections in some embodiments.

FIG. **5**C illustrates a cross sectional view of the first section **515** viewed along line **5**C-**5**C of FIG. **5**A. As shown in FIG. **5**C, the first sections **515** may each include a rectangular or square cross section. The first sections **515** may each include a first wall or inner wall **512**, a second wall or outer wall **514**, a third wall or upper wall **516**, and a fourth wall or lower wall **518**. The width dimension of each first section **515** may be defined by the distance between the outer surfaces of the inner and outer walls **512**, **514**. The height dimension of each first section **515** may be defined by the distance between the outer surfaces of the upper and lower walls **516**, **518**.

In some embodiments, at least the height dimension of each first section **515** may be configured to be greater than or about the outer diameter of each magnetic element **520** such that when the magnetic elements **520** may be positioned around the second sections **540** and at least partially received within the annular recesses defined by the second sections **540**, the magnetic element **520** may not extend above the upper wall **516** or below the lower wall **518** of the first section **515**. With this configuration, when the magnetic induction plasma system **500** may be integrated in the chamber system **200**, the upper walls **516** and the lower walls **518** of the first sections **515** may provide support or load-bearing surfaces for supporting other chamber components and/or the magnetic induction plasma system **500**, while the magnetic elements **520** may not contact or bear the weight of adjacent or nearby chamber components of the chamber system **200**. Further, because the magnetic elements **520** may not extend beyond the upper and lower walls **516**, **518**, the upper-most and the lower-most surface profiles of the magnetic induction plasma system **500** may be substantially defined by the upper and lower walls **516**, **518**, respectively, which may be substantially flat. This profile may improve the compatibility of the magnetic induction plasma system **500** with the chamber system **200** given that several components may include a plate-like structure or planar surface, such as the faceplate **217**, the ion suppressor **223**, the showerhead **225**, and so on.

Although not shown in FIG. **5**A, the first sections **515** may include apertures formed in the upper walls **516** for introducing or flowing one or more precursors into the plasma source **510** for generating a plasma therein. The first sections **515** may further include apertures formed in the lower walls **518** for releasing at least portions of the plasma products generated inside the plasma source **510**. In some embodiments, the first sections **515** may not include the upper and lower walls **516**, **518**. The plasma source **510** may be formed in part by the inner and outer walls **512**, **514** and in part by the adjacent plates or surfaces of the chamber components of the chamber system **200**.

As can be seen from the description of the embodiments shown in FIGS. **4**A-**4**F and FIGS. **5**A-**5**C, the term toroidal or toroidal shape used herein is not limited to a torus or toroidal shape with uniform or consistent width and/or height dimensions along the extension of the toroidal shape. Further, in some embodiments, the toroidal shape may include consistent or similar cross sections along the extension of the toroidal shape, such as the embodiments shown in FIGS. **4**A-**4**F, while in some embodiments, the toroidal shape may include varying cross sections along the extension of the toroidal shape, such as the embodiments shown in FIGS. **5**A-**5**C. Moreover, in some embodiments, the toroidal extension may define a substantially circular shape, such as the toroidal extension of the embodiment shown in FIG. **4**A, while in some embodiments, the toroidal extension may define a multi-sided shape which may include one or more arcs and one or more substantially straight segments. For example, the first sections **515** of the embodiments shown in FIGS. **5**A-**5**C may be or include arcuate extensions while the second sections **540** may be or include substantially straight extensions. Furthermore, in some embodiments, the plasma source may not include arcuate sections and both the first and/or second sections may be or include substantially straight extensions. Accordingly, the plasma source may include all arcuate sections, all substantially straight sections, or a combination thereof.

FIG. **6**A illustrates select components of an exemplary process chamber system **600**, which may include a magnetic induction plasma system **610**. The process chamber system **600** may further include a gas inlet assembly **605** and a faceplate **617** positioned upstream of the magnetic induction plasma system **610** and a gas distribution component **615** positioned downstream of the magnetic induction plasma system **610**. The process chamber system **600** may include additional components downstream of the gas distribution component **615** similar to those described with reference to FIG. **2**A, such as one or more gas distribution components, various components defining a substrate processing region, a substrate support, and so on, which are not illustrated in FIG. **6**A, but will be readily appreciated to be encompassed within a chamber incorporating the components illustrated.

During film etching, deposition, and/or other semiconductor processes, one or more precursors may be flowed through the gas inlet assembly **605** into a gas supply region **658**. The precursors may include any gas or fluid that may be useful for semiconductor processing, including, but not limited to, process gases, treatment gases, carrier gases, or any suitable gas or gas mixtures for semiconductor processing. The faceplate **617** may facilitate uniform distribution of the precursors from the gas supply region **658** into the magnetic induction plasma system **610**. Similar to the faceplate **217** described above with reference to FIGS. **2**A and **2**B, the faceplate **617** may include apertures **659** configured to direct flow in a substantially unidirectional manner such that the precursors may flow into the magnetic induction plasma system **610**, but may be partially or fully prevented from backflow into the gas supply region **658** after traversing the faceplate **617**. As shown in FIG. **6**A, the magnetic induction plasma system **610** may define one or more flow passages **612** that may be aligned with or intersect only portions or select areas or regions of the faceplate **617**. Accordingly, in some embodiments, the apertures **659** may be formed only in select areas of the faceplate **617** corresponding to the defined flow passages **612**, as shown in FIG. **6**A.

In some embodiments, the apertures **659** may be formed outside the select areas, such as across or throughout a central area or substantially the entire surface area of the faceplate **617**. To direct the flow of the precursors into the magnetic induction plasma system **610** or to limit or prevent the flow of the precursors outside the magnetic induction plasma system **610**, the process chamber **600** may optionally include an intermediate plate **614**. The intermediate plate **614** may be positioned in an abutting relationship with the faceplate **617** downstream of the faceplate **617** to prevent or block the flow of the precursors through the apertures **659** formed outside the select areas. The intermediate plate **614** may include one or more cutouts **616** that may be aligned with the openings of the flow passages **612** defined by the magnetic induction plasma system **610** to allow the precursors to flow into the magnetic induction plasma system **610**. In some embodiments, intermediate plate **614** may facilitate retrofit operations with faceplate designs that define a more uniform distribution of apertures across the component, although intermediate plate **614** may be omitted in some embodiments.

Although a single plate is illustrated in FIG. **6**A, the gas distribution component **615** may include one or more plates that may control distribution of the plasma products generated inside the magnetic induction plasma system **610** downstream into the substrate processing region. In some embodiments, the gas distribution component **615** may include an ion suppressor, similar to the ion suppressor **223** described above with reference to FIG. **2**, configured to control the passage of the activated gas from the magnetic induction plasma system **610**. The activated gas may include ionic, radical, and/or neutral species, which may also be collectively referred to as plasma products. Similar to the ion suppressor **223**, the ion suppressor of the gas distribution component **615** may include a perforated plate with a variety of aperture configurations to control or suppress the migration of charged particles or species out of the magnetic induction plasma system **610** while allowing uncharged neutral or radical species to pass through the ion suppressor. In some embodiments, the gas distribution component **615** may further include a gas distribution assembly or showerhead, similar to the gas distribution assembly or dual channel showerhead **225** described above with reference to FIG. **2**. The showerhead of the gas distribution component **615** may allow for separation of various precursors outside of the substrate processing region prior to being delivered into the processing region while facilitating even mixing of the precursors as they exit the showerhead.

Although both an ion suppressor and a showerhead are described herein as exemplary parts that the gas distribution component **615** may include, in some embodiments, the gas distribution component **615** may include only one of the ion suppressor or the showerhead but not the other, or may not include either of the ion suppressor or the showerhead. In some embodiments, the gas distribution component **615** may include other suitable plates or gas distribution control mechanisms. In some embodiments, the gas distribution component **615** may not include any gas distribution control mechanism. In some embodiments, the process chamber system **600** may not include the gas distribution component **615** at all. In other words, the plasma generated inside the magnetic induction plasma system **610** may be distributed directly into the substrate processing region without passing through any distribution control or filtering mechanism.

With reference to FIGS. **6**B and **6**C, the magnetic induction plasma system **610** will be described in more detail. FIG. **6**B shows a top perspective view of the magnetic induction plasma system **610**, and FIG. **6**C shows a cross sectional view of the magnetic induction plasma system **610** viewed along line **6**C-**6**C in FIG. **6**B. Although not shown in FIGS. **6**B and **6**C, similar references including toroidal axis, radial direction, azimuthal direction, and toroidal extension or direction as shown in FIG. **4**A, may be used for description of the embodiment shown in FIGS. **6**B and **6**C. One difference between the embodiments shown in FIGS. **6**B and **6**C and the embodiments shown in FIGS. **4**A-**5**C may include that the magnetic induction plasma system **610** may include two plasma sources: a first plasma source **620** and a second plasma source **630**. In some embodiments, first plasma source **620** may be, or include any of the characteristics of, the previously described sources, and may incorporate second plasma source **630** within an inner annular radius of the first plasma source **620**. The first plasma source **620** and the second plasma source **630** may define two toroidal shapes having a common center and a common toroidal axis. The second plasma source **630** may be positioned radially inward from the first plasma source **620**. Accordingly, the first plasma source **620** may also be referred to as the outer plasma source **620**, and the second plasma source **630** may also be referred to as the inner plasma source **630**.

With reference to FIG. **6**B, each of the first and second plasma sources **620**, **630** may include multiple sections. The first plasma source **620** may include one or more first section **622**, which may be or include conductive sections, and one or more second sections **624**, which may be or may include dielectric sections or dielectric breaks, arranged in an alternating manner such that the first sections **622** may be electrically isolated or insulated from each other by the second sections **624**. The first sections **622** and the second sections **624** may be fluidly coupled with each other to define a first plasma circulation channel. At least a portion of ionized or charged species of the plasma products may circulate inside the first plasma circulation channel and may pass through at least a portion or portions of the first sections **622** and/or a portion or portions of the second section **624** along the toroidal extension of the first plasma source **620**.

Similarly, the second plasma source **630** may include one or more third sections **632**, which may be or may include conductive sections, and one or more fourth sections **634**, which may be or may include dielectric sections or dielectric breaks, arranged in an alternating manner such that the third sections **632** may be electrically isolated or insulated from each other by the fourth sections **634**. The third sections **632** and the fourth sections **634** may be fluidly coupled with each other to define a second plasma circulation channel. At least a portion of the ionized or other charged species of the plasma products generated inside the second plasma source **630** may circulate through at least a portion or portions of the third sections **632** and/or a portion or portions of the fourth section **634** along the toroidal extension of the second plasma source **630**.

In the embodiments shown in FIG. **6**B, the first plasma source **620** may include four first sections **622** and four second sections **624**, and the second plasma source **630** may include two third sections **632** and two fourth sections **634**.

Although four first sections **622** and four second sections **624** are shown for the first plasma source **620**, the first plasma source **620** may include more or fewer of the first sections **622** and/or the second sections **624**. Similarly, although two third sections **632** and two fourth sections **634** are shown for the second plasma source **630**, the second plasma source **630** may include more or fewer of the third sections **632** and/or the fourth sections **634**.

The four second sections **624** of the first plasma source **620** may be positioned at an equal distance from each other along the toroidal extension of the first plasma source **620** and may be positioned apart from each other by an azimuthal angle of about 90 degrees. The two fourth sections **634** of the second plasma source **630** may also be positioned at an equal distance from each other along the toroidal extension of the second plasma source **630** and may be positioned apart from each other by an azimuthal angle of about 180 degrees. Additionally, each of the fourth sections **634** of the second plasma source **630** may be positioned at an azimuthal angle different from each of the second sections **624** of the first plasma source **620**. The fourth sections **634** of the second plasma source **630** may be positioned at an azimuthal angle different from the azimuthal angles of the two nearby second sections **624** of the first plasma source **620** by about 45 degrees, or any other suitable angle. Positioning the second sections **624** of the first plasma source **620** and the fourth sections **634** of the second plasma source **630** at different azimuthal angles may limit interference or arcing issues between the first sections **622** of the first plasma source **620** and the third sections **632** of the second plasma source **630**, especially when high voltages may be applied during the plasma ignition period.

The extension of each first section **622** and the extension of each third section **632** along the toroidal extension of the respective first and second plasma sources **620**, **630** may be characterized by an arcuate shape, while the extension of each second section **624** and the extension of each fourth section **634** may be substantially straight. With respect to the first plasma source **620**, a ratio of the extension of each first section **622** to the extension of each second section **624** may be greater than or about 1.5:1, 2:1, 2.5:1, 3:1, 3.5:1, 4:1, 4.5:1, 5:1, 6:1, 7:1, 8:1, 9:1, 10:1, or greater. With respect to the second plasma source **630**, a ratio of the extension of each third section **632** to the extension of each fourth section **634** may be greater than or about 1.5:1, 2:1, 2.5:1, 3:1, 3.5:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:1, 10:1, or greater. The greater the ratio of the extension of the arcuate first sections **622** to the substantially straight second sections **624**, or the greater the ratio of the extension of the arcuate third sections **632** to the substantially straight fourth sections **634**, the closer the circulation channel inside the first and second plasma sources **620**, **630** for the plasma current may resemble a circle to facilitate the circulation of the plasma current, and the more stable and uniform the plasma generated therein may be. However, the extension of the second and/or fourth sections **624**, **634** may be maintained above at least a threshold value such that potential arc faults between the first and/or third sections **622**, **632** coupled with either side of a second or fourth section **624**, **634** or other arcing issues that may be caused by the high voltage especially during plasma ignition may be limited or eliminated.

Similar to the second sections **540** of the plasma source **510** shown in FIGS. **5**A and **5**B, each of the second and/or fourth sections **624**, **634** may define an annular recess for receiving therein at least a portion of a magnetic element (not shown in FIGS. **6**B and **6**C). As discussed above, the annular recesses may be configured such that when the magnetic elements may be received therein, the magnetic elements may not contact the upper and lower chamber components when the magnetic induction plasma system **610** may be integrated in the chamber system **600**. Coils may be wrapped around at least a portion of each magnetic element. Electrical energy may be supplied to the coils for generating a plasma inside each of the first plasma source **620** and the second plasma source **630**. Once the plasma may be generated inside the first and second plasma sources **620**, **630**, at least a portion of the ionized or charged species of the plasma products may circulate inside the first and second plasma channels under the induced electric field along the toroidal extension of the first and second plasma sources **620**, **630**, while the neutral or radicals species of the products, as well as a portion of the ionized or charged species, may flow through the flow passages **612** into the substrate processing region.

With reference to FIG. **6**B and using the first sections **622** and the second sections **624** of the first plasma source **620** as an example, the coupling between the first sections **622** and the second sections **624** and the coupling between the third sections **632** and the fourth sections **634** will be described in more detail. Each of the second sections **624** may include a hollow cylindrical body **640** oriented along the toroidal extension of the first plasma source **620** and two flanges **642***a*, **642***b* configured at the opposite ends of the hollow cylindrical body **640**. Each of the first sections **622** may include an arcuate tubular body **644** extending parallel to the toroidal axis of the first plasma source **620**. The arcuate tubular body **644** may define one or more of the flow passages **612** described above with reference to FIG. **6**A. The flow passages **612** may include a substantially consistent width dimension. Accordingly, the opening of each first section **622** for the precursors to flow into the first plasma source **620** and the opening of each first section **622** for releasing the plasma products generated may include substantially the same width dimensions as the arcuate tubular body **644**, with the width dimensions measured along the radial direction.

The first section **622** may include an arcuate first or inner wall **646**, an arcuate second or outer wall **648**, and two sidewalls **650** (only one labeled in FIG. **6**B) connecting the ends of the inner wall **646** and the outer wall **648**. The inner wall **646**, outer wall **648**, and sidewalls **650** together may form the tubular body **644**. Each of the sidewalls **650** may include an aperture **652** formed therethrough that may be aligned with the hollow centers of the cylindrical bodies **640** of the adjacent second sections **624** such that fluid communication between the first sections **622** and the second sections **624** may be established. In some embodiments, the sidewalls **650** of the first section **622** may include flanged or outwardly tapered portions **654** to provide sufficient surface area for coupling with the flanges **642** of the second sections **624**. The sidewalls **650** of the first section **622** and the flanges **642** of the second sections **624** may be coupled with each other via bolts, screws, glue, adhesive, welding, brazing, and any suitable bonding or coupling mechanism. To prevent gas leakage, the exterior surface of each sidewall **650** may be formed with an annular recess **656** (shown in FIG. **6**C) for receiving a sealing ring, such as an O-ring or any other suitable sealing elements, which may be pressed against the flanges **642** to create a seal therebetween when the first sections **622** and the second sections **624** may be coupled with each other.

With reference to FIG. **6**C, each of the first sections **622** may include an inner width dimension which may be defined as the distance between the inner surfaces of the inner wall

646 and the outer wall 648 along the radial direction. Each of the second sections 624 may include an inner diameter which may be defined as the inner diameter of the cylindrical body 640. The inner width dimension of each first section 622 may be substantially the same or similar to the inner diameter of each second section 624 such that the flow of the ionized or charged species of the plasma products inside the first plasma source 620 may be facilitated to maintain the plasma generated therein. Each of the first sections 622 may include a height dimension which may be defined as the extension of the first sections 622 parallel to the toroidal axis. The height dimension of each first section 622 may be similar to or greater than the inner width dimension of each first section 622 or the inner diameter of each second sections 624. A ratio of the height dimension of each first section 622 to the inner width dimension thereof or to the inner diameter of each second section 624 may be greater than or about 1:1, 1.5:1, 2:1, 2.5:1 3:1, or greater. Each of the third sections 632 of the second plasma source 630 may be configured with an inner width dimension and a height dimension the same as or similar to those of the first sections 622 of the first plasma source 620, and the fourth sections 634 of the second plasma source 630 may be configured with an inner diameter the same as or similar to the inner diameter of the second sections 624 of the first plasma source 620. Consequently, the height dimension of each third section 632 may be similar to or greater than the inner width dimension of each third section 632 or the inner diameter of each fourth sections 634 of the second plasma source 630. A ratio of the height dimension of each third section 632 to the inner width dimension thereof or to the inner diameter of each fourth section 634 may be greater than or about 1:1, 1.5:1, 2:1, 2.5:1 3:1, or greater.

Configuring the height dimension of each first and/or third sections 622, 632 greater than the inner width dimension thereof, and thus greater than the inner diameter of each second and/or fourth sections 624, 634, may not only create the annular recesses around the second and/or fourth sections 624, 634 for receiving the magnetic elements therein, but may also help to sustain the plasma current circulating through the cylindrical bodies 640 and the first and third sections 622, 632 along the toroidal extension of the first and second plasma sources 620, 630. This may be partly because the plasma current, as well as the electrical field driving the current, may be maintained at a distance away from the faceplate 617 above, and at a distance away from the gas distribution component 615 below, each of which may be constructed of metals and may affect the plasma current flow or the electrical field.

In some embodiments, the magnetic induction plasma system 610 may further include dielectric ring members 660*a*, 660*b* (see FIG. 6B) coupled to the opposite, e.g., top and bottom, rims of the arcuate tubular bodies 644. The dielectric ring members 660*a*, 660*b* may electrically isolate or insulate the first and third sections 622, 632 from other metal chamber components adjacent the magnetic induction plasma system 610 when the magnetic induction plasma system 610 may be incorporated to the chamber system 600. The dielectric ring members 660*a*, 660*b* may further electrically isolate or insulate the first sections 622 from each other and may insulate the third sections 632 from each other when the magnetic induction plasma system 610 may be incorporated to the chamber system 600 and may contact the other metal components of the chamber system 600. The dielectric ring members 660*a* coupled to the top of the arcuate tubular bodies 644 may define a first planar supporting surface and may be configured to support at least one of the gas inlet assembly 605 or the faceplate 617 at the first planar supporting surface when the magnetic induction plasma system 610 may be incorporated into the chamber system 600. The dielectric ring members 660*b* coupled to the bottom of the arcuate tubular bodies 644 may define a second planar supporting surface, and the magnetic induction plasma system 610 may be supported by the gas distribution component 615 at the second planar supporting surface.

With further reference to FIGS. 6B and 6C, the first plasma source 620 may include one or more monitoring windows or apertures 662 configured at the outer walls 648 of the first sections 622. Although not shown, the second plasma source 630 may also include one or more monitoring windows or apertures configured at the walls of the third sections 632. Optical, electrical, chemical, or other suitable probes or monitoring mechanisms may be coupled to the monitoring window 662 for monitoring the properties of the plasma generated inside the first and second plasma sources 620, 630. The data collected by the monitoring mechanism may be utilized to set up a closed-loop or feedback control for adjusting automatically the power, current, etc., supplied to the coils to generate a stable plasma with desired properties and/or composition of the plasma products generated.

FIGS. 7A-7C show schematic views of an exemplary plasma system in operation according to embodiments of the present technology. FIG. 7A schematically illustrates a top view of a process chamber system 700 incorporating a magnetic induction plasma system 710 similar to that described above with reference to FIG. 5. FIG. 7B schematically illustrates a cross sectional view of a process chamber system 700*b* incorporating a magnetic induction plasma system 710*b* as a direct plasma source. FIG. 7C schematically illustrates a cross sectional view of a process chamber system 700*c* incorporating a magnetic induction plasma system 710 as a remote plasma source.

With reference to FIG. 7B, the magnetic induction plasma system 710*b* may be positioned directly above the substrate processing region 720 within which a substrate may be supported by a pedestal 730. One or more precursors may be flowed into the magnetic induction plasma system 710*b* via a gas inlet assembly 705. A power source 715 may be coupled with the magnetic induction plasma system 710*b* for supplying electrical energy to the magnetic induction plasma system 710*b* for generating a plasma from the precursors. The magnetic induction plasma system 710*b* may include a plasma source that may be configured with an open bottom such that the plasma products, including ionic, radical, and/or neutral species, as well as any carrier gases, may be flowed directly onto the substrate to be processed. The plasma products exiting the magnetic induction plasma system 710*b* may diffuse into a cone shaped volume such that by the time the plasma products may reach the pedestal 730, the plasma products may be diffused onto the entire surface area of the substrate to be processed.

Depending on the distance between the magnetic induction plasma system 710*b* and the pedestal 730, the size of the substrate to be processed, and other factors, the magnetic induction plasma system 710*b* may be configured with a proper width dimension such that full coverage of the substrate to be processed by the plasma products may be ensured and waste of precursors for generating the plasma products may be minimized. As discussed above, the width dimension may be defined as the distance between the inner surfaces of the inner and outer walls, denoted as W in FIG. 7A. In some embodiments, the width dimension may be greater than or about 10% of the radius of the process chamber **700**, denoted as R in FIG. **7**A. In some embodiments, the width dimension may be greater than or about 20%, 30%, 40%, 50%, 60%, 70%, 80%, or more of the radius R of the process chamber **700**.

With reference to FIG. **7**C, the magnetic induction plasma system **710***c* may be integrated into the chamber system **700***c* as a remote plasma source. The chamber system **700***c* may include an ion suppressor **740** configured to control the passage of the plasma products generated. Similar to the ion suppressor **223** discussed above with reference to FIG. **2**, the ion suppressor **740** may include a perforated plate with a variety of aperture configurations to control or suppress the migration of charged particles or species out of the magnetic induction plasma system **710***c* while allowing uncharged neutral or radical species to pass through the ion suppressor **740**. The chamber system **700** may further include a gas distribution assembly or showerhead **750**, similar to the gas distribution assembly or dual channel showerhead **225** described above with reference to FIG. **2**. The showerhead **750** may facilitate even distribution of the neutral or radical species into the processing region **720** and onto the substrate to be processed. In some embodiments, the showerhead **750** may further allow for separation of various precursors outside of the substrate processing region **720** prior to being delivered into the processing region while facilitating even mixing of the precursors as they exit the showerhead **750**. Given that the ion suppressor **740** and/or the showerhead **750** may facilitate even distribution of select plasma products into the processing region **720** and onto the substrate, the magnetic induction plasma system **710***c* may include a width dimension that may be similar to or less than the width dimension of the magnetic induction plasma system **710***b* when configured as a direct plasma source. In various embodiments, the width dimension of the magnetic induction plasma system **710***c* may be greater than or about 20%, 30%, 40%, 50%, 60%, 70%, 80%, or more of the radius R of the process chamber **700**.

FIGS. **8**A-**8**C show schematic views of an exemplary plasma system in operation according to embodiments of the present technology. FIG. **8**A schematically illustrates a top view of a process chamber system **800** incorporating a magnetic induction plasma system **810** similar to the magnetic induction plasma system **610** described above with reference to FIG. **6**. FIG. **8**B schematically illustrates a cross sectional view of a process chamber system **800***b* incorporating a magnetic induction plasma system **810***b* as a direct plasma source. FIG. **8**C schematically illustrates a cross sectional view of a process chamber system **800***c* incorporating a magnetic induction plasma system **810***c* as a remote plasma source.

The configuration of the process chamber systems **800***b*, **800***c* may be similar to those of the process chamber systems **700***b*, **700***c*, respectively, except that the magnetic induction plasma system **810***b*, **810***c* may each include two toroidal shaped plasma sources: an inner plasma source **812** and an outer plasma source **814**. The plasma products generated by the inner plasma sources **812***b*, **812***c* may be flowed onto a circular central region of the substrate to be processed, and the plasma products generated by the outer plasma sources **814***b*, **814***c* may be flowed onto an annular or outer region of the substrate surrounding and overlapping with at least a peripheral portion of the central region.

To ensure full coverage of the substrate by the plasma products released from the inner and outer plasma sources **812**, **814**, the width dimensions of the inner and outer plasma sources **812**, **814** may each be greater than or about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, or greater of the radius of the process chamber **800**. In the embodiment of FIG. **8**C, because the ion suppressor **840** and/or the showerhead **850** may facilitate even distribution of the plasma products onto the substrate, the width dimensions of the inner and outer plasma sources **812***c*, **814***c* may be less than the width dimensions of the inner and outer plasma sources **812***b*, **814***b* of the embodiment of FIG. **8**B. While the plasma sources **812**, **814** may be configured with greater width dimensions to ensure full coverage of the substrate by the plasma products, the width dimensions may be kept under certain values such that the interference between the magnetic fields generated by the plasma currents inside the inner and outer plasma sources **812**, **814** may be minimized. To further limit such interference, a sufficient distance between the inner and outer plasma sources **812**, **814** may also be maintained. In some embodiments, the inner and outer plasma sources **812**, **814** may each be configured with a width dimension between about 10% and about 30% of the radius of the process chamber **800**. The distance between the inner and outer plasma sources **812**, **814** may be maintained at about 50% or more of the width dimension of the plasma sources **812**, **814**. Although the inner and outer plasma sources **812**, **814** are illustrated to have substantially similar width dimensions, the inner and outer plasma sources **812**, **814** may have dissimilar or different width dimensions.

The various embodiments of the magnetic induction plasma systems described above may utilize an LLC resonant half bridge circuit driving scheme. Conventional plasma generating systems may typically utilize a full bridge circuit driving scheme. The LLC resonant half bridge circuit may generally be more reliable and cost effective as compared to the conventional full bridge circuit for plasma generation. The LLC resonant half bridge circuit may yield higher power transfer efficiency for the magnetic induction plasma systems described herein. Compared to a conventional plasma generating system using full bridge circuit driving scheme, the LLC resonant half bridge circuit driving scheme for the magnetic induction plasma systems may require significantly lower power to ignite and/or sustain the plasma while yield similar dissociation of the precursor gases. For example, the magnetic induction plasma system as described herein may require a plasma ignition power of about 1,000 W, 800 W, 600 W, 400 W, 200 W, or less, and may require a plasma sustaining power of only ½, ⅓, or less of the ignition power. In contrast, a plasma generating system utilizing full bridge circuit driving scheme may require 10,000 W or more for plasma ignition and/or sustaining partly due to energy loss on the driving circuitry.

Further, conventional plasma generating systems utilizing a full bridge circuit driving scheme may allow for limited power adjustment. The magnetic induction plasma systems utilizing an LLC resonant half bridge circuit driving scheme may allow for power adjustment from 0 W to about 1,000 W or higher. For example, the power may be modulated by adjusting the driving voltage, current, and/or frequency. Increasing the driving voltage and/or the current may increase the power output, while decreasing the driving frequency may increase the power output. Generally, higher power output may yield a higher dissociation rate of the precursor gases. By adjusting the power output, the dissociation rate of the precursor gases may be modulated to achieve desired composition of the plasma products.

Moreover, in the embodiments where the magnetic induction plasma system may include an inner toroidal plasma source and an outer toroidal plasma source, different levels of power may be supplied to the inner and outer toroidal plasma sources. For example, a relatively higher power, such as about 300 W to about 1,000 W may be supplied to the outer toroidal plasma source, whereas a relatively lower power, such as about 100 W to about 600 W may be supplied to the inner toroidal plasma source. Although different levels of power may be supplied to the inner and outer toroidal plasma sources, the driving frequencies for the inner and outer toroidal plasma sources may match such that the induced electrical fields in or near the inner and outer toroidal plasma sources may not cancel each other out.

The magnetic induction plasma systems described herein may operate to generate a plasma at a wide frequency range from about 50 kHz to about 500 MHz. However, a lower frequency may yield higher power transfer efficiency because high frequency may lead to power loss in the magnetic elements. In some embodiments, the LLC resonant half bridge circuit may supply a current to the plurality of coils at a frequency between about 100 kHz and about 20 MHz, between about 200 kHz and about 10 MHz, between about 400 kHz and about 1 MHz, or any suitable range. The magnetic induction plasma systems may also operate at a very wide pressure range. The operational pressure inside the toroidal plasma sources may be maintained between about 1 mTorr and about 500 Torr, or even higher pressure. The precursor may be flowed at various flow rates into the plasma source such that a pressure within the plasma source may be maintained between about 1 mTorr and about 500 Torr, or between about 10 mTorr and about 300 Torr, or between about 15 mTorr and about 200 Torr, or any suitable range. Very stable plasmas may be generated and maintained by the magnetic induction plasma systems described herein at the various power levels, frequency ranges, and/or the pressure ranges. This may be in part because once the plasma may be ignited, the coil and the plasma current may operate in a manner similar to the primary and secondary coils of a transformer to sustain the plasma generated in a stable state.

In the preceding description, for the purposes of explanation, numerous details have been set forth in order to provide an understanding of various embodiments of the present technology. It will be apparent to one skilled in the art, however, that certain embodiments may be practiced without some of these details, or with additional details.

Having disclosed several embodiments, it will be recognized by those of skill in the art that various modifications, alternative constructions, and equivalents may be used without departing from the spirit of the embodiments. Additionally, a number of well-known processes and elements have not been described in order to avoid unnecessarily obscuring the present technology. Accordingly, the above description should not be taken as limiting the scope of the technology. Additionally, methods or processes may be described as sequential or in steps, but it is to be understood that the operations may be performed concurrently, or in different orders than listed.

Where a range of values is provided, it is understood that each intervening value, to the smallest fraction of the unit of the lower limit, unless the context clearly dictates otherwise, between the upper and lower limits of that range is also specifically disclosed. Any narrower range between any stated values or unstated intervening values in a stated range and any other stated or intervening value in that stated range is encompassed. The upper and lower limits of those smaller ranges may independently be included or excluded in the range, and each range where either, neither, or both limits are included in the smaller ranges is also encompassed within the technology, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included.

As used herein and in the appended claims, the singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise. Thus, for example, reference to “a precursor” includes a plurality of such precursors, and reference to “the layer” includes reference to one or more layers and equivalents thereof known to those skilled in the art, and so forth.

Also, the words “comprise(s)”, “comprising”, “contain(s)”, “containing”, “include(s)”, and “including”, when used in this specification and in the following claims, are intended to specify the presence of stated features, integers, components, or operations, but they do not preclude the presence or addition of one or more other features, integers, components, operations, acts, or groups.

The invention claimed is:

**1**. A magnetic induction plasma system, comprising:

a first plasma source including a plurality of first sections and a plurality of second sections fluidly coupled with each other such that at least a portion of plasma products generated inside the first plasma source circulate through at least one of the plurality of first sections and at least one of the plurality of second sections inside the first plasma source, wherein each of the plurality of second sections comprises a dielectric material, wherein the plurality of first sections and the plurality of second sections are arranged in an alternating manner such that the plurality of first sections are electrically insulated from each other at least in part by the plurality of second sections;

a plurality of first magnetic elements, wherein each of the plurality of first magnetic elements defines a closed loop and is positioned around one of the plurality of second sections; and

wherein the first plasma source defines a first toroidal shape, the first toroidal shape having a first toroidal extension and a first toroidal axis perpendicular to the first toroidal extension, wherein each of the plurality of first sections includes a first dimension parallel to the first toroidal axis, wherein each of the plurality of second sections includes a second dimension parallel to the first toroidal axis, wherein the first dimension is greater than the second dimension such that the plurality of second sections defines a plurality of annular recesses, wherein each of the plurality of annular recesses is configured to receive one of the plurality of first magnetic elements such that the magnetic induction plasma system is integratable into a semiconductor processing chamber having a gas inlet assembly disposed upstream of the magnetic induction plasma system, wherein the plurality of first sections is configured to support a planar surface of the gas inlet assembly, and wherein the plurality of annular recesses is configured to allow the plurality of magnetic elements to be disposed below the planar surface of the gas inlet assembly without contacting the planar surface of the gas inlet assembly.

**2**. The magnetic induction plasma system of claim **1**, wherein each of the plurality of first sections comprises a first opening and a second opening, wherein each of the plurality of first sections and the corresponding first and second openings define a flow passage parallel to the first toroidal axis, wherein the first opening of each of the plurality of first sections is configured to receive a precursor into the corresponding first section and generate the plasma products inside the first plasma source, wherein the second opening of each of the plurality of first sections provides access for the generated plasma products to flow from the corresponding first section.

3. The magnetic induction plasma system of claim 1, further comprising a plurality of first dielectric ring members each positioned at a top rim of one first section of the plurality of first sections and a plurality of second dielectric ring members each positioned at a bottom rim of one first section of the plurality of first sections such that the plurality of first sections are electrically insulated from each other when the magnetic induction plasma system is integrated into the semiconductor processing chamber and positioned between metal components of the semiconductor processing chamber along the first toroidal axis.

4. The magnetic induction plasma system of claim 3, wherein the semiconductor processing chamber further comprises a gas distribution assembly, wherein the gas distribution assembly is positioned downstream of the magnetic induction plasma system, wherein the plurality of first dielectric ring members defines a first planar supporting surface and is configured to support the planar surface of the gas inlet assembly, and wherein the plurality of second dielectric ring members defines a second planar supporting surface and is configured to be supported by a planar surface of the gas distribution assembly.

5. The magnetic induction plasma system of claim 1, wherein each of the plurality of first sections includes an arcuate tubular body.

6. The magnetic induction plasma system of claim 1, wherein each of the plurality of second sections comprises a pair of flanges configured at two opposite ends of each second section and configured to couple each second section with two adjacent first sections.

7. The magnetic induction plasma system of claim 1, wherein each of the plurality of first sections includes a first extension along the first toroidal extension, wherein each of the plurality of second sections includes a second extension along the first toroidal extension, a ratio of the first extension to the second extension is between about 10:1 and about 2:1 such that circulation of at least a portion of plasma products inside the first plasma source is facilitated.

8. The magnetic induction plasma system of claim 1, further comprising:

a second plasma source defining a second toroidal shape, the second toroidal shape having a second toroidal extension and a second toroidal axis perpendicular to the second toroidal extension, the second toroidal axis aligned with the first toroidal axis, wherein the second plasma source is positioned radially inward from the first plasma source, the second plasma source comprises a third section and a fourth section, at least one of the third section or the fourth section comprises a dielectric material; and

at least one second magnetic element defining a closed loop and positioned around at least one of the third section or the fourth section.

9. The magnetic induction plasma system of claim 8, wherein the at least one second magnetic element is positioned at an azimuthal angle different from an azimuthal angle of each of the plurality of first magnetic elements such that interference between an electric field generated by each of the plurality of first magnetic elements and an electric field generated by the at least one second magnetic element is reduced.

10. The magnetic induction plasma system of claim 8, wherein the first plasma source and the second plasma source are configured such that the plasma products exiting the first plasma source diffuses onto a first region of a substrate, wherein the first region defines a substantially annular shape, wherein the plasma products exiting the second plasma source diffuses onto a second region of the substrate, wherein the second region defines a substantially circular shape, and the first region and the second region overlap.

11. The magnetic induction plasma system of claim 8, further comprising:

a plurality of electrically coupled first coils each being configured around at least a portion of each of the plurality of first magnetic elements; and

a second coil being configured around at least a portion of the at least one second magnetic element, wherein the magnetic induction plasma system is driven by an LLC resonant half bridge circuit, wherein:

the LLC resonant half bridge circuit is configured to supply a first current to the plurality of electrically coupled first coils at a frequency that matches a frequency at which the LLC resonant half bridge circuit is configured to supply a second current to the second coil.

12. The magnetic induction plasma system of claim 11, wherein the LLC resonant half bridge circuit is configured to supply the first current and the second current at a frequency between about 100 kHz and about 20 MHz.

13. The magnetic induction plasma system of claim 11, wherein the LLC resonant half bridge circuit is configured to supply a first power to the plurality of electrically coupled first coils and to supply a second power to the second coil, the first power being greater than the second power.

14. A semiconductor processing chamber, comprising:

a magnetic induction plasma system, wherein the magnetic induction plasma system comprises:

a first plasma source having a first toroidal shape having a first toroidal axis, the first plasma source defining a first annular recess of the first toroidal shape; and

a first magnetic element forming a closed loop and positioned around a portion of the first plasma source, at least a portion of the first magnetic element being received within the first annular recess, wherein:

the first plasma source includes a first wall and a second wall at least in part defining a flow passage parallel to the first toroidal axis, wherein a top rim of the first wall and a top rim of the second wall at least in part define a first opening configured to receive an unexcited precursor into the first plasma source configured to generate plasma products therefrom, wherein a bottom rim of the first wall and a bottom rim of the second wall further at least in part define a second opening providing access for the generated plasma products to flow from the first plasma source, wherein the first and second walls define a width of the first plasma source along a radial direction of the first toroidal shape, wherein the top rims of the first and second walls define a width of the first opening along the radial direction of the first toroidal shape, wherein the bottom rims of the first and second walls define a width of the second opening along the radial direction of the first toroidal shape, and wherein the first opening, the second opening, and the first plasma source are characterized by the same width along the radial direction of the first toroidal shape.

15. The semiconductor processing chamber of claim 14, wherein the magnetic induction plasma system further comprises:

a second plasma source having a second toroidal shape and coaxially aligned with the first plasma source, the second plasma source positioned radially inward from the first plasma source, the second plasma source defining a second annular recess of the second toroidal shape; and

a second magnetic element forming a closed loop and positioned around a portion of the second plasma source, at least a portion of the second magnetic element being received within the second annular recess, wherein:

the second plasma source includes a third opening configured to receive the unexcited precursor into the second plasma source configured to generate plasma products therefrom and a fourth opening providing access for the generated plasma products to flow from the second plasma source, wherein the third opening, the fourth opening, and the second plasma source are characterized by the same width measured along a radial direction of the second toroidal shape.

16. The semiconductor processing chamber of claim 15, wherein the first magnetic element is positioned at a first azimuthal angle, and the second magnetic element is positioned at a second azimuthal angle different from the first azimuthal angle.

17. The semiconductor processing chamber of claim 14, further comprises a gas inlet assembly having a planar surface and disposed upstream of the magnetic induction plasma system, wherein the magnetic induction plasma system is configured to support the planar surface of the gas inlet assembly.

18. The semiconductor processing chamber of claim 17, wherein the gas inlet assembly comprises a first gas delivery member and a second gas delivery member, wherein the second gas delivery member defines the planar surface of the gas inlet assembly to be supported by the magnetic induction plasma system, wherein the first gas delivery member comprises a first flange surrounding a protruding portion of the first gas delivery member, wherein the second gas delivery member comprises a second flange surrounding a recess defined by the second gas delivery member, wherein the recess is configured to receive the protruding portion, wherein the second flange is configured to support the first flange to define a gas supply region between the first gas delivery member and the second gas delivery member when the protruding portion is received in the recess, and wherein the gas supply region provides fluid access to the first plasma source for the unexcited precursor.

19. The semiconductor processing chamber of claim 14, further comprises a gas distribution assembly having a planar surface and disposed downstream of the magnetic induction plasma system, wherein the magnetic induction plasma system is configured to be supported by the planar surface of the gas distribution assembly.

20. The semiconductor processing chamber of claim 19, further comprises a dielectric ring member positioned at the bottom rims of the first and second walls and contacting the planar surface of the gas distribution assembly.

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